**Science and Mathematics Education Centre**

# Teaching and Learning Genetics with Multiple Representations

**Chi-Yan Tsui**

**This thesis is presented for the Degree of**
**Doctor of Philosophy**
**of the**
**Curtin University of Technology**

**April 2003**

# DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature: ………………………………

(Chi-Yan Tsui)

Date: 24 April 2003

# Abstract

This study investigated the secondary school students' learning of genetics when their teachers included an interactive computer program *BioLogica* in classroom teaching and learning. Genetics is difficult to teach and learn at school because it is conceptually and linguistically complex for students who have little or no prior knowledge about it. Yet genetics is now central to learning and research in biomedical sciences and is essential for understanding contemporary issues such as genetic engineering and cloning. Interactive multimedia programs such as *BioLogica* have provided new opportunities for learning as these programs feature multiple external representations (MERs) of knowledge in different formats, including visual-graphical and verbal-textual and at different levels of organisation. Users can manipulate and observe the behaviour of these MERs. Ainsworth (1999) summarised three functions of MERs claimed by researchers in supporting learners—to provide complementary information or processes, to constrain interpretations of phenomena and to promote construction of deeper understanding of the domain.

Using an interpretive, case-based research approach with multiple methods and multiple sources of data, this study was guided by two foci of inquiry—teachers' integration and implementation of *BioLogica* in their classroom teaching, and students' learning with *BioLogica* alongside other resources. The theoretical framework drew on perspectives from educational psychology, the conceptual learning model in science education, and cognitive/computational sciences. Student learning was interpreted using a multidimensional conceptual change framework (Tyson, Venville, Harrison, & Treagust, 1997)—social/affective dimension in terms of students' interests and motivations, epistemological dimension in terms of genetics reasoning of six types (Hickey & Kindfield, 1999), and ontological dimension in terms students' gene conceptions (Venville & Treagust, 1998). Teaching and learning with *BioLogica* were also analysed and interpreted using Ainsworth's three functions of MERs. Necessary techniques including triangulation were used to increase the rigour of data analysis and interpretation in keeping with the qualitative research tradition.

The study was conducted during the years 2001 and 2002 at six classroom sites across four senior high schools of different contexts in the metropolitan Perth area in Western Australia. Five teachers and their Year 10 students (four classes) and Year

12 students (two classes)—117 students (90 girls and 27 boys), aged from 14 to 18, —participated in the study. Data were collected in response to the initial research questions and the reformulated case-specific research questions. The findings in terms of general assertions were generated from within-case and cross-case analyses and interpretations.

Findings of the study suggest that teachers idiosyncratically incorporated (rather than integrated) *BioLogica* activities in their classroom teaching based on their beliefs and referents for normal classroom teaching. The teachers' implementation and scaffolding of student learning with *BioLogica* were affected by their knowledge of the software and beliefs about its usefulness based on the salient features of the MERs rather than their functions. Institutional support, technical issues, and time constraints were the possible barriers for using *BioLogica* in teaching. The findings also suggest that most students were motivated and enjoyed learning with *BioLogica* but not all who were actively engaged in the activities improved their genetics reasoning. Mindfulness (Salomon & Globerson, 1987) in learning with the *BioLogica* MERs, learning together with peers, scaffolded learning within the zone of proximal development (Vygotsky, 1978) were deemed important to students' conceptual learning. The postinstructional gene conceptions of most students were not sophisticated and were generally intelligible-plausible (IP) but not intelligible-plausible-fruitful (IPF). While most students identified two salient features of *BioLogica* MERs, visualisation and instant feedback, some students who substantially improved their reasoning believed that these two features helped their understanding of genetics. Overall, students exhibited social/affective (motivational) and epistemological conceptual change but little or no ontological change.

The findings have implications for further and future research. First, Thorley's status analysis is useful in analysing multidimensional conceptual change (Tyson et al., 1997). Second, MERs have provided new learning opportunities and challenges for classroom learning and science teacher education. Third, there is urgency for improving Year 10 genetics teaching and learning. Fourth, the notion of multiple representations is promising in unifying theoretical constructs in psychology, cognitive/computational sciences, science education and science teacher education.

# Dedication

I dedicate this thesis with much love to my mother Siu-Kuen Siu Tsui,
my caregiver, my first and lifelong teacher, my mentor and my friend,
whose intelligence, optimism and love have always been
a source of encouragement, power and promise
through the vicissitudes
of my life.

# Acknowledgements

First of all, I would like to thank the teachers and students for their participation, warm support and kind help during my research in their classrooms.

My sincere thanks go to Professor David Treagust, my thesis supervisor. David is a wonderful supervisor, a mentor and a colleague. He has allowed me to develop my own academic interests yet guided me to keep focused and be parsimonious. Not only have I learnt from him about research in science education, but I have also learnt the essence of scholarly writing. I am grateful for his availability, patience, encouragement, support and his wisdom in guiding me through my study during our many hours of discussion and for his meticulousness in reading my work.

I gratefully acknowledge the advice and support of Dr Paul Horwitz (Concord Consortium, USA) who allowed me to use *BioLogica* for research in Australian schools; Associate Professor Mark Hackling (Edith Cowan University) and Dr Grady Venville (Curtin University of Technology) for providing me with sound advice in planning for the study; and Associate Professor Geoff Giddings (Curtin University of Technology) for his help in my data collection during the second case study. I also thank Dr Dorit Maor (Murdoch University) for providing me with advice on a possible doctoral proposal and my former colleague Dr Sunny Lee for helping me to settle down at the Science and Mathematics Education Centre (SMEC) in 2000.

I would like to thank Peter Coles and the Curtin WebCT Team whose support was indispensable for my online data collection. I gratefully acknowledge Jennie Benjamin of the Curtin University Counselling Services for arranging the disability support for my study. Many thanks are due to my two helpers, Megan Hill and Susan Rennie, who came to the case schools to help observe lessons and carefully transcribed the lessons and interview recordings. My thanks also go to the Department of Education, Employment and Training (DEET) of the State of Victoria, for permission to use the material from the Australian Science Education Project (ASEP) Handbook Series in the online tests and interview tasks.

I must thank Professor Barry Fraser, the director of SMEC, for providing the excellent research facilities and fostering an intellectually conducive environment for doctoral students. I am grateful to Professors John Malone and Darrell Fisher for their encouragement. I am also grateful to Rosalie Wood and Anthony Meston for their kind support during my study. I thank my fellow doctoral colleagues Robyn

Chien and Gail Chittleborough for their feedback on my data interpretation and my writing. Our discussions are very useful. My thanks also go to Lily Settelmaier, Jaya Earnest, Sing Huat Poh and other doctoral colleagues for their camaraderie and other staff members for their support in one way or another. I enjoyed our conversations which often enlightened my thinking and enriched my experiences.

I sincerely thank my friends—David Tong in Queensland; David Pang, Anthony Ma, Don Mackay and Belinda Fowler in New Zealand; and Dr Ho-chia Chueh of the National Taiwan University—for their support of my passion towards earning a PhD.

Finally, with all my heart, I thank my wife Irene and my son David for their persistent support, love and understanding when we could not be always together.

# Table of Contents

# List of Tables

# List of Figures

# Prologue

One morning in April 2000, I cautiously entered a small conference room in a hotel in Auckland. I was the earliest to arrive. There in the room, I was warmly greeted by Professor Barry Fraser who was holding a small tea gathering for Curtin University's doctoral students in New Zealand. We had had a brief conversation before other people arrived. My attendance in this tea gathering marked the beginning of my long journey as a doctoral student and then a part-time teacher educator in the Science and Mathematics Education Centre (SMEC) of the Curtin University of Technology in Perth, Western Australia. My journey is a long one, both metaphorically and literally, but also a productive and fruitful one.

The doctoral study reported in this thesis has brought together my lifelong fascinations about science and my interests in using interactive and motivating methods in teaching biology in my Hong Kong school. In particular, my hope of using computers in supporting student learning has become a reality. The study has also drawn upon my two decades of teaching genetics in pre-university biology classes and my learning experiences with the computer. Over these years, I have learnt programming languages—FORTRAN, BASIC, PASCAL, C++, JAVA and HTML—although I never did well in programming with these languages. Nonetheless, such learning experiences have helped me better appreciate the design and use of the latest interactive multimedia and the human-computer interactions for reasoning and problem solving. At times, I had some unrealistic hopes of using my programming skills to create my own software to enhance student learning. Then, with the shift in the popularity of learning theories among science educators—from a Piagetian perspective to social constructivist and sociocultural perspectives—I have come to know that the computer should be considered as a tool to learn with and that social interactions are important in such learning.

In my personal life, the computer has actually become an important part of me. I became hearing-impaired in midlife after an illness. I have since been wearing a hearing aid. Recently, the state-of-the-art programmable digital hearing aids have helped me communicate much better with other people. Over the past few years, the digital technology has also made me very excited as I have the opportunities of using the latest information and communication technologies (ICT) to conduct research for my doctoral study in Australian classrooms. Perhaps I may be one of a few profoundly hearing-impaired people to complete a doctoral degree in science education. Here is the story of my journey—my lifelong teaching and learning, and my research work, which have now culminated in this thesis that documents my doctoral study. The first chapter is an introduction to my study and an overview of this thesis.

# Chapter 1

# Introduction

> I have argued in numerous papers and presentations that an important cause of the deficiencies in thinking skills of students at all educational levels is the overreliance of educators on a singular form of knowledge representation. That is, teachers and professors typically assess students' learning using only one form of representation (e.g., multiple-choice test, essay, worksheet, or research paper). Representing what learners know in only a single way requires only a single form of cognitive representation that constrains students' understanding of whatever they are studying… Numerous examples of limitations in thinking are chronicled throughout the educational literature, but most examples are not even acknowledged because of the prevalence of the practice. This state of affairs is ironic given the emphasis in the research and practice in instruction on multiple representations. Multiple modality, multi-image, and multimedia development have dominated instructional development for the last 30 years. (Jonassen, 2001, p. 321)

## 1.0 Overview

In this first chapter, my intent is to provide readers with an introduction and a tour guide to the whole thesis. This chapter begins by introducing the background of and rationale for this study. The next part briefly summarises the theoretical framework that has allowed me to frame the research questions and select the most appropriate research approach for this study. The chapter then gives an overview of the study, its significance and limitations. The last part introduces the nine chapters in this thesis and then shares with readers my experience of writing with technology.

## 1.1 Background of the Study

I once taught and enjoyed teaching biology and science in an English-medium Catholic school in Hong Kong for 21 years before living in New Zealand and Australia. While I was teaching, I quite often thought that biology had still not been transformed into "an intellectually satisfying discipline like physics or chemistry" (Watson, 2001, p. 17). I gradually became dissatisfied with the lack of higher order thinking being engendered in the teaching and learning of school biology.

Perhaps biology, as we knew it now, has changed tremendously to be more intellectually satisfying, partly because of the recent impacts of genetics and molecular biology. Genetics is a topic which I like to teach most because I believe that students can learn reasoning and problem solving in a way unique to the study of biology. While I was teaching, I had always been interested in how knowledge can be represented in different ways, particularly using audiovisual aids alongside the verbal or textual format in presenting information to students. This also included talking science in Chinese (my first language) and English (my second language). My teaching experiences informed me that using Chinese concept words in teaching biology helped my Hong Kong students to develop a better understanding of the concepts by investing on their own everyday knowledge that they had acquired outside the school in their first language. This appeared to be one of my rudimentary conceptions of the benefits of using more than one representation without the necessary jargon to describe it.

I was first introduced to the notion of *multiple representations* by the late Professor David Squires[1] (2000) during the Institute entitled *Teaching and Learning Science, Mathematics and Technology in the Information Age* held in 2000 in the Science and Mathematics Education Centre (SMEC), Curtin University of Technology. This institute provided me with insights into the recent cognitive/computational perspectives of *multiple external representations (MERs).* The inception of the ideas of this study came from my review of the literature on teaching and learning of genetics and on the latest developments in using information and communication technologies (ICT), especially interactive multimedia, in supporting teaching and learning of science and mathematics (Jacobson & Kozma, 2000).

My rich experiences of teaching pre-university biology and my experience of classroom research into learning genetics with an interactive multimedia program called *GenScope* (Concord Consortium, 2001; Horwitz & Christie, 2000) in New Zealand schools (Tsui, 1999, 2000) have allowed me to better understand the issues of learning with computers. While the doctoral coursework that I took in the SMEC enlightened me with some new insights into the contemporary issues of science education research, my visits to some schools in Perth in 2000, too, helped me better

[1] Professor David Squires of the University of London, who was an adjunct teaching staff of the SMEC, passed away in 2001 due to cancer; and the tragic news saddened me with shock long after I knew it.

understand science education in Western Australia. My teaching experience as a part-time course tutor in the SMEC since 2001 further enriched my understandings of Australian science and mathematics education. Taken together, all these experiences provided me with a useful background, in one way or another, for undertaking this doctoral study.

During this study, particularly while attending the SMEC seminars or Australian and international conferences, I had the opportunities of meeting a number of well known science educators from Australia, New Zealand, the USA, the UK, Sweden and Germany. I also had the opportunities to have conversations from time to time with three Australian science educators—Mark Hackling, Grady Venville and Allan Harrison—the authors of the published work which I consider as the major references for my thesis. Such valuable experiences of meeting these researchers have further helped my understanding of their published works which I had been reading during my study.

## 1.2 Rationale for the Research

Researchers over the past two decades have unanimously found that genetics remains conceptually and linguistically difficult to teach and learn in high schools (see for example, Bahar, Johnstone, & Hansell, 1999; Hackling & Treagust, 1984; Johnstone & Mahmoud, 1980; Stewart, 1982; Venville & Treagust, 1998; Wood, 1996). Yet genetics is central to learning and research in biomedical sciences and is essential for understanding some important contemporary issues such as genetically modified foods and cloning. Genetics is difficult because it is one of those domains that requires learners to use multilevel thinking (Johnstone, 1991). There is also a large and esoteric vocabulary of genetics, of which students have little prior knowledge, and which constitutes a linguistic barrier for student learning (see for example, Carey, 1986; Pearson & Hughes, 1988b).

As learning always involves some ways of representing information, science teachers have long been using different representational techniques in the classroom to communicate ideas to students by voice, writing, and gestures, and so on. These representations are also called external representations. From the conceptual change learning perspective, representability is essential for making difficult concepts intelligible (Thorley, 1990). Recently, researchers in cognitive/computational sciences have begun to look at the pedagogical functions of using more than one form of computer-based representation in educational software or multiple external representations (MERs) (van Someren, Reimann, Boshuizen, & de Jong, 1998). These MERs, as some researchers claimed, can support learning by complementary information and processes, by constraining interpretations (or misinterpretations) of phenomena, and by promoting a deeper understanding of concepts but not without new costs and challenges (Ainsworth, 1999; Ainsworth, Bibby, & Wood, 1997).

*BioLogica* (Concord Consortium, 2001) is a new genre of educational software known as a hypermodel (Horwitz & Tinker, 2001) that features MERs for learning introductory genetics in high schools. *BioLogica* allows students to manipulate objects of genetics represented at these different levels of organisation—DNA, genes, chromosomes, cells, organisms and pedigrees—and observe the behaviour of these objects constrained by the principles of genetics. As Horwitz and Tinker (2001) predicted, the use of powerful, content-based modelling and data analysis tools like *BioLogica* are likely to make contributions to improve science learning and the hypermodel "could be the key to realizing this dream in real classrooms" (p. 5).

On the basis of the aforementioned literature review, this study explored the use of *BioLogica* in learning of genetics in classrooms involving teachers teaching in authentic situations. The findings are likely to contribute to our knowledge about the use of multiple representations in teaching and learning of genetics, new pedagogies for using interactive multimedia to engender understanding, and science teachers' education in the information age. Given that representability can increase intelligibility of concepts, MERs provide new opportunities for learning genetics. Furthermore, the issues of multiple representations are "critical to the entire field of learning" (Jonassen, 2001, p. 237) (also see the epigraph of this chapter). Jonassen's comment rightly summarises the rationale for this study.

## 1.3 Theoretical Framework

In this study, I view learning within social constructivist and sociocultural theoretical frameworks (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Duit & Treagust, 1998; Tobin, 1990). In the 1980s and early 1990s, *conceptual change* was a term for the mainstream constructivist approaches (Duit & Treagust, 1998). Conceptual change learning perspectives have their roots in both science education (Hewson, 1981, 1996; Hewson & Thorley, 1989; Posner, Strike, Hewson, & Gertzog, 1982) and developmental psychology (Carey, 1985; Vosniadou, 1994; Vosniadou & Brewer, 1992). The theoretical framework of Posner et al.'s (1982) conceptual change model is the leading paradigm that has been guiding research and instructional practices in science education for many years (Vosniadou, 1999).

The social constructivist perspective holds that knowledge cannot be transmitted but must be constructed by the learners and that knowledge construction involves both individual and social processes (Driver et al., 1994). The study also utilised the sociocultural perspectives (Vygotsky, 1978; Werstch, 1985) which have not been considered by most conceptual change researchers until recently (see Hodson & Hodson, 1998; Howe, 1996). In particular, I used Vygotsky's notion of the *zone of proximal development* (Vygotsky, 1978) and the role of *cultural tools,* both symbolic tools (e.g., language), or technical tools (e.g. the computer), which serve in mediating higher level thoughts. First, it follows that the more knowledgeable others—the teacher or more capable peers—play an important role in student learning, especially the social interactions in the classroom. Second, Vygotsky's notion of *tools* has been extended to view the computer as a *cognitive tool* or a *mindtool* (Jonassen, 2000) in supporting student learning.

These theoretical perspectives have provided the rationale for me to adopt the multidimensional framework (Tyson, Venville, Harrison, & Treagust, 1997) for interpreting conceptual change along the affective/social, epistemological, and ontological dimensions. The use of Tyson et al.'s framework in this study was also built upon Venville's (1997) research into students' understanding of the gene concept and Harrison's (1996) study on students' learning of chemistry concepts using multiple analogical models. One focus in this study is on the fruitfulness in the conceptual change model, which has not been adequately addressed in previous research, as this is not easy to determine. In reviewing the literature, I found Thorley's (1990) status analysis categories to be most useful in this regard and that few studies had adopted them in analysing conceptual status. Indeed, Thorley's framework has greatly enriched my analysis of students' conceptual change in this study (see Chapter 8).

## 1.4 Research Questions

Two broad research foci were originally proposed with more specific research questions subsumed within each. The first focus is about how and why teachers use the interactive multimedia program *BioLogica* and other resources and their effects on their students' learning of genetics. The second focus is about students' interactions with the multiple representations in *BioLogica* and other resources when they are learning genetics. The original foci and research questions are summarised as follows:

Focus 1: The extent to which the teacher-designed classroom learning environment —using the multimedia *BioLogica* and other teaching resources—is conducive to students' development of higher order learning in genetics

Research questions:

1. How do teachers integrate the multimedia program into their classroom teaching and students' learning of genetics?
2. What are teachers' beliefs, actions and referents in the integration and implementation of the multimedia program?
3. How effective is the learning environment in engendering students' reasoning in genetics?

Focus 2: Students' interactions with the multiple representations in *BioLogica* and other teaching material when learning to develop reasoning in genetics.

Research questions:

4. What actors affect students' interactions with the multiple representations in the multimedia program?
5. In what ways do their students' interactions with these multiple representations contribute to their higher order learning?
6. Do the computer-based multiple representations bring about students' conceptual change in their understanding of genetics concepts?

As we shall see in the following chapters of this thesis, these initial research questions guided but were reformulated to suit the content and context of the four case studies and to address issues associated with emergent themes in the findings of the case studies.

## 1.5 Research Approach

Given the complexity of classroom learning using an interactive multimedia program, an interpretive research methodology (Erickson, 1986, 1998; Gallagher, 1991) is deemed most suitable for this research. An interpretive research approach allows the researcher to explore research questions in classroom learning that cannot be answered fully or satisfactorily by other methods. It follows that I adopted an interpretive approach with a multiple, embedded case study methodology (Merriam, 1988, 1998; Stake, 1995; Yin, 1994) for conducting the case studies in four Perth schools involving five teachers and their six classes (four Year 10 and two Year 12 classes). The teacher in the second case school was a student teacher who was studying in a university in Perth during the research.

Data from multiple sources, both qualitative and quantitative, were collected using three major data collection methods: interviewing students and teachers, observing classrooms, and collecting documents and other artefacts. The data sources included the transcripts of semi-structured interviews, records of online tests with multiple choice items and open-ended questionnaire items, computer data log files, classroom observation field notes and lesson transcripts from audiotapes and videotapes, my reflective journals, field notes and teacher's handouts and other documents collected in the case schools.

Quantitative methods (online test scores comparisons) and qualitative methods (analysis of non-numerical data from interviews and classroom discourse) were combined for more meaningful interpretation of the students' learning experiences with *BioLogica*. In keeping with the interpretive research paradigm, Guba and Lincoln (1989) suggested *credibility/transferability*, *dependability* and *confirmability* were respectively used in place of *internal/external validity*, *reliability* and *objectivity* in experimental research using a positivist research paradigm. To increase *credibility*, I tried to match the participants' constructed realities with my reconstructions attributed to them by using the techniques suggested by Guba and

Lincoln such as *prolonged engagement*, *persistent observation and member checks*. Analysis (both quantitative and qualitative) and interpretation of data have generated explanations that led to formulation of assertions to be confirmed or disconfirmed through triangulations (e.g., data, methodological and theoretical triangulation) (Denzin & Lincoln, 1994; Erickson, 1986, 1998; Fraser & Tobin, 1991; Gallagher, 1991) (see section 3.8).

## 1.6 Overview of this Study

The data collection period of the study extended over two years (2001 and 2002) and the study was conducted in four senior high schools in the metropolitan area of Perth, Western Australia. Five science and biology teachers and their six classes of Years 10 and 12 students participated in the study (see Table 1.1).

Table 1.1

*Summary of the Case Information in This Study*

| Time of the Study | School | Type of School | Teacher (pseudo-nyms) | Exper-ience (years) | Year/ Class | Number of Participating Students | | | Student Age (years) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | All | Girls | Boys | |
| April to June 2001 | A | State co-ed | Mr Anderson | 27 | 10 | 24 | 11 | 13 | 14-15 |
| June to July 2001 | B | State co-ed | Miss Bell | 0 | 10 | 28 | 17 | 11 | 14-15 |
| March to July 2002 | C | Independent girls' | Ms Claire | 20 | 10 / 1 | 25 | 25 | 0 | 14-15 |
| | | | Mrs Dawson | 25 | 10 / 2 | 23 | 23 | 0 | 14-15 |
| July to September 2002 | D | State co-ed | | | 12/Bio[a] | 6 | 3 | 3 | 17 |
| | | | Ms Elliott | 9 | 12/HBio[b] | 11 | 10 | 1 | 16-18 |
| Total | (4 case schools; 5 teachers and 6 classes) | | | | | 117 | 90 | 27 | |

[a] Biology Class for Tertiary Entrance Examinations (TEE).

[b] Human Biology Class for Tertiary Entrance Examinations (TEE).

The case studies in Schools A and B took place in 2001 and those in School C and D were in 2002. In each of the four case schools, I spent three to ten weeks observing most of the lessons and interviewing the teachers and the students and collecting documents and other artefacts. Guba and Lincoln's (1989) suggestion of *prolonged engagement* and *persistent observation* underpinned my actions all through the case studies. In more than one hundred school visits, I spent hundreds of hours at the school sites to conduct the research.

## 1.7 Significance of the Study

The study is significant for the following reasons: (1) the study is likely to contribute to better understanding of the benefits and costs in using multiple representations in teaching and learning of genetics and other science domains; (2) the study is likely to add new knowledge about students' multidimensional conceptual change in learning about reasoning and problem solving in genetics; (3) the findings about motivational outcomes and their possible impact on cognitive engagement point to a new research agenda about intentional conceptual change (Sinatra & Pintrich, 2003b); (4) the findings about the preservice teacher's pedagogical content knowledge (Shulman, 1987) may have implications for science teacher education in the information age.

## 1.8 Limitations of this Study

The limitations of the study will be discussed in the methods chapter (Chapter 3), the results chapters (Chapters 4 to 7), and the discussion and conclusions chapter (Chapter 9) of the thesis.

In brief, the limitations of this study are of two types. The first types came from the inherent limitations of interpretive case-based research approach which I will discuss in Chapter 3. Some of these more relevant to this study will be again discussed in Chapter 9 by referring to some individual case studies. The second type of limitations was associated with the rigour in data collection or the quality of the data being collected in the particular case studies. My hearing-impairment was one of such limitations. I am fortunate to have had a helper[2] to assist my classroom observations and transcribe the lessons and interview recordings. The incomplete data collected—because of minimising the intrusion to participants' normal classroom life and respecting their wishes—was another limitation of this type. By considering the limitations of the study throughout the thesis, I hope I can remind myself and readers of this thesis that, as Stake (1995) put it, "the report is just one

[2] A helper—paid by a disability support fund of the Curtin University of Technology—helped me in classroom observations, twice in each case school, and transcribed the lessons and interview recordings; there were two helpers over the entire data collection period (see Acknowledgements).

person's encounter with a complex case" (p. 123). Nevertheless, I have tried to argue my case with evidence.

## 1.9 Thesis Structure and Production

This thesis contains nine chapters organised in a rather standard structure with four major parts—an introduction (Chapter 1), theoretical background in literature and research methodology (Chapters 2 and 3), research results of this study (Chapters 4 to 7), synthesis of the results, discussion and conclusions (Chapters 8 and 9).

Chapter 1 is an introduction and tour guide to the whole thesis. This is followed by Chapter 2 reviews and synthesises three separate but related bodies of literature relevant to this research: (1) reasoning in the history of genetics from Mendel to Watson and Crick; (2) the conceptual change models used in interpreting student learning in this study; and (3) theoretical perspectives about multiple representations. Chapter 3 about methodology and methods is unique because I delineate these two constructs by drawing on Strauss and Corbin's (1998) definitions. Chapters 4 to 7 document the four case studies in Schools A, B, C and D of rather different contexts in a chronological order. Chapter 4 is about the first case study in a state co-educational school involving a very experienced science teacher and his Year 10 class learning with *BioLogica*. Chapter 5 portrays the story of a preservice teacher having practice teaching in School B where she attempted to use *BioLogica* in her teaching of a Year 10 class. Chapter 6 reports the case study in School D—an independent girls' school with laptop computers—where the two teachers used *BioLogica* alongside other online interactive multimedia for teaching genetics in their two Year 10 classes. Chapter 7 reports the fourth case study in a state senior school where the teacher used *BioLogica* in teaching her students in two Year 12 classes who were preparing for the Tertiary Entrance Examinations (TEE). Chapter 8 compares and contrasts students' conceptual learning through cross-case analyses in order to construct abstractions across the cases and to look for common threads. On the basis of the assertions in each of the results chapters and the common threads identified in Chapter 8, Chapter 9 brings together all the chapters for an overall discussion and more cross-case analyses which are then followed by general conclusions, implications, suggestions for further and future research and a summary of limitations of this study.

To end this chapter, I would like to share with readers some of my experiences in writing this thesis. Writing began in mid-2001, right after I had finished my first two case studies. Since then, I had revised and improved each chapter draft many times before it was finalised with feedback from multiple sources—my thesis supervisor, my colleagues in the SMEC, comments from the audiences during conference presentations and the reviewers of manuscripts submitted for publication. From time to time, I revisited the old literature and searched for the new. As for the references, I always tried to read the original published works—such as Mendel's paper and Morgan and his students' books or Watson and Crick's journal articles in 1953—and watch out for the latest publications such as *Time*'s interview with Watson in February 2003 (see Chapter 2). Searching and retrieving reference materials through the electronic database of the library saved me much time of going to the library and photocopying the materials. However, scholarly writing is not easy.

Writing with a word processor in a powerful computer is fast and efficient. Indeed, I often edited several chapters simultaneously with *Word* updating the parallel changes in different places to increase the coherence of the whole thesis. With a scanner and other software tools, I could easily import graphics into the thesis or create others for illustration. Not only were the hundreds of reference citations conveniently managed by the *EndNote* software, but the verbal data (such as interview transcripts) stored in hundred of files were also easily coded, indexed, searched and retrieved using the *NUD*IST*[3] and *NVivo*[4] software and imported into the thesis as direct quotes to support the claims and assertions. When finalising the thesis, the table of contents and list of figures and tables can be automatically generated to minimise errors and omissions. Nevertheless, it is still the human intellect—involved in thinking, revising, editing and proof reading—that is most crucial for improving the quality of writing. The computer does free us of the tedious chores that frustrated the old-timers who used the typewriter which did not always type right. We can write a better thesis yet faster now, can't we? Or is this claim just an oxymoron? The next chapter of the thesis will review the relevant literature.

---

[3] NUD*IST (Non-numerical Unstructured Data Indexing, Searching and Theorising) is a software tool for analysing verbal data (Gahan, 1998).

[4] NVivo is the latest version of the NUD*IST software (Gibbs, 2002).

# Chapter 2

# Literature Review

> He [Mendel] was well educated and extremely appropriately, primarily as a physicist and mathematician, and brought the precision of those austere disciplines to the problem of heredity, as others had recommended before, but rarely attempted. Indeed, it's almost as if he was destined to do the work he did: he was exactly the right kind of thinker in the right place at the right time, surrounded by fine scientists but far ahead of them all.
>
> (Tudge, 2000, p. 14)

## 2.0 Overview

Instead of writing three chapters on the review of the literature related to this research, I attempt to synthesise the three parts into a single chapter in which each part serves to inform a major aspect of this research. The literature review in this chapter lays the groundwork for interpreting the teaching and learning of genetics for reasoning and understanding using multiple representations. However, some bodies of literature related to the methodology and other specific aspects will be given in Chapter 3 and other chapters.

The first part reviews the historical development of scientific reasoning of Mendel and the early Mendelians up to the time when Morgan (1926) published his gene theory and then of Watson and Crick (1953a; 1953b) who discovered the double helix structure of the DNA molecule. These biologists made important contributions towards the development of genetics of today. The second part of this chapter is about the conceptual change model which constitutes the major framework for interpreting student learning in this research. The highlight of this part is an updated literature review of a multidimensional framework for interpreting conceptual change along the social/affective, epistemological and ontological dimensions. The third part introduces the cognitive/computational perspectives about multiple representations that provide a theoretical framework for examining the possible learning benefits or costs when students learn with interactive multimedia in general and the software *BioLogica* (Concord Consortium, 2001) in particular. Finally, a synopsis brings together these three parts to form the bedrock for the whole thesis.

## 2.1 Reasoning in the History of Genetics

### 2.1.1 Introduction

The first part of this chapter reviews the literature to seek response to one question—what reasoning strategies were involved in the development of scientific ideas in genetics since Mendel's time. Given that my focus is on reasoning, perhaps Darden's (1992) suggestion that "[f]rom the perspective of philosophy of science, the general issues of representation and reasoning become how to represent scientific theories and how to find strategies for reasoning in theory change" (p. 251) is a good guideline for writing this part.

Thagard (1992b) considered Charles Darwin's (1859) evolutionary theory on a par with Lavoisier's chemical revolution but does not count "[t]he two major developments [Mendelism and the double helix model of DNA] in biology since Darwin"(p. 153) as conceptual revolutions. However, as Bowler (1989) pointed out, "Darwinism and Mendelism are the two important steps needed to create modern biology" (p. 56). More importantly, it was Mendel who cracked the puzzle of heredity that had perplexed Darwin for his whole life. Unfortunately, Darwin did not read Mendel's paper (Tudge, 2000). Watson and Crick's double helix model of DNA has provided a plausible and fruitful explanation for how the gene might replicate, mutate, and be expressed. Since the Mendelian gene became molecular, the science of genetics has been pivotal in the biological sciences and has had important impacts on today's human affairs both in providing benefits and presenting humans with ethical issues since the last century. Just after the centenary of the rediscovery of Mendel's work, geneticists completely mapped the human genome sequence promising practical consequences. For example, in April 2003, scientists succeeded in mapping the genome of the deadly virus that causes Severe Acute Respiratory Syndrome (SARS) making it possible to develop a vaccine against SARS that killed more than one hundred people in 21 countries (CNN, 2003a).  At the same time, the human genome project has opened up the Pandora's box from which emerge some controversial moral and ethical issues such as genetically modified foods and cloning.

Instead of chronicling an exhaustive historical review about the science of genetics, I have tried to focus on the scientific reasoning of some selected geneticists who contributed to the development from the classical Mendelism to molecular genetics. According to Darden's (1991) philosophical analysis, the reasoning strategies in the development of Mendelian genetics can be generalised into three types: (1) strategies for producing new ideas, (2) strategies for assessing a theory, and (3) strategies for anomaly resolution. These will be the foci of the first part of the review.

### 2.1.2 Mendel's Classical Experiments

Gregor Johann Mendel (1822-1844) was a monk in a monastery at Brno, Moravia of the Austro-Hungarian Empire (now part of the Czech Republic). In those days, the Brno Natural Science Society of which Mendel was a member included most of the great biologists of the nineteenth century mainland Europe. Mendel had an avid interest in plant breeding because of his family background and a brief education in science and mathematics in the University of Vienna. In 1856, Mendel, while in the monastery, began to inbreed pea plants (*Pisum sativum*) in the garden by means of repeated self-pollination until about 1863 (Fisher, 1936; Henig, 2000; Tudge, 2000). These classical experiments marked the genesis of a new science.

According to his original paper (Mendel, 1865a) and its interpretations by various authors (Bowler, 1989; Fisher, 1936; Henig, 2000; Tudge, 2000), Mendel traced the results of his breeding experiments (genetic crosses) between strains of peas plants differing in seven well-defined characters, such as stem length (tall or dwarf) or seed shape (round or angular) (see Table 2.1). For example, all the dwarf plants (with long stems) produced dwarf offspring only in the first generation, but of the tall plants, only about one third were true breeding or pure-bred. Mendel then crossed the pure-bred tall and dwarf plants and found that all the resulting hybrids were tall. Crossing these hybrids resulted in a mixture of pure-bred dwarf, hybrid tall, and pure-bred tall plants in the ratio 1:2:1. He used the term *dominant* (*dominirende* in German) (Mendel, 1865b) to describe the characters of the hybrid and *recessive* (same in German) (Mendel, 1865b) for those which became latent in the process and then reappeared unchanged in the progeny.

Mendel extended his experiments to hybridisation of parent plants differing in more than one well-defined character (dihybrid cross) and found the 9:3:3:1 ratio in the second generation. Mendel concluded that such *characters* (*Markmale* in German) were determined by *factors* (*Elemente* in German) that were contributed equally by both parents and that sorted themselves among the offspring according to simple statistical rules. He summarized these findings in two principles (later to be known as Mendel's laws). Mendel's essential discovery appeared to be his ideas about the *segregation explanation*—"that one material unit causes one character, that hybrids have paired units, and that the pairs separate (segregate) in a pure, uncontaminated way in the formation of germ cells of hybrids" (Darden, 1991, p. 45). Accordingly, what Mendel referred to might be just the character or Merkmal which a unit or Element determines but not the unit itself.

Table 2.1

*Summary of Mendel's (1865a) Monohybrid Crosses in which Parents Differed in One Differentiating Character (partly based on Russell, 2002, p. 262, Table 10.1).*

| Parent Characters | Hybrid Characters (F1) | Results of Crossing Hybrids including Reciprocal Crosses (F2) | F2 Ratio |
|---|---|---|---|
| Round x angular seeds | All round | 5774 round, 1850 angular[a] | 2.96:1 |
| Yellow x green seeds | All yellow | 6022 yellow; 2001 green | 3.01:1 |
| Grey x white[b] seeds<br>Purple x white petals | All grey seeds and purple petals | 705 purple; 224 white | 3.15:1 |
| Inflated x white petals | All inflated | 882 inflated; 299 pinched | 2.95:1 |
| Green x yellow pods | All green | 428 green; 152 yellow | 2.82:1 |
| Axial x terminal flowers | All axial | 651 axial; 207 terminal | 3.14:1 |
| Long x short stems | All long | 787 long; 277 short | 2.84:1 |

[a] Non-round seeds are more commonly translated as *wrinkled* but careful research by Henig (2000) suggested that the German word *kantig* translates more accurately as *angular*.

[b]It was known later that a single gene controls both the seed coat and the flower petal colour trait (Russell, 2002).

Tudge (2000) pointed out that Mendel's knowledge in physics and mathematics, particularly statistics, was crucial to his success in making sense of heredity "because he brought precision and purity of physics to the subject…" (p. 29) and "he studied about 10,000 different plants minutely. He knew that the patterns he would be looking at were of statistical nature, and unless he looked at a lot he would not achieve valid results" (p. 82). In multiple representations parlance (see section 2.3), I would say that Mendel's use of mathematical representations in reasoning enabled him to propose a plausible explanation for heredity which none of his predecessors had been able to figure out.

He was lucky to have chosen garden peas for his experiments but his success as the first geneticist was far beyond serendipity. According to Tudge (2000), Mendel's brilliant thinking was enlightened by his fine teachers and mentors such as J. Schreiber, F. C. Snapp, Johann Doppler and Franz Unger, and influenced directly or indirectly by famous biologists of the nineteen-century such as Matthias Schleiden (1804-1881), a German botanist who proposed the cell theory; Johannes Purkinje (1787-1869), a Czech physiologist, and Rudolf Carl Virchow (1821-1902), a German pathologist. Mendel's work, according to Tudge, surpassed all these people in terms of the contribution to science but was appreciated by none of his contemporaries leaving him disappointed and frustrated (Henig, 2000). However, just as he predicted before his death when he said, "Meine Zeit wird schon kommen"[5] (Henig, 2000, p. 171), his contribution was ignored but not forgotten. He was soon to be called the father of genetics.

### 2.1.3 Rediscovery of Mendel's Paper

Mendel (1865a) read the paper about his findings in two meetings of the Brno Natural Science Society in 1865 and published it in the society's journal in the following year. However, from the time of its publication until 1900, Mendel's paper "had passed entirely unnoticed by the scientific circles of Europe…completely overlooked, except for the citations in Focke's Pfanzenmischlinge, and a single citation of Hoffman…" (Fisher, 1936, p. 1). The relative obscurity of the local journal not being widely circulated was often considered as the first reason why Mendel's published work in 1866 was not recognised (Bowler, 1989). The second reason is that Mendel's work was, as Bowler (1989) put it, "ahead of his time" (p. 94).

In 1900, Mendel's work was independently rediscovered by three biologists: Correns in Germany, de Vries in Holland and von Tschermak in Austria. It should be noted that in 1900 none of the three rediscovers saw the segregation explanation as being a promising line of research for developing a general theory of genetics as did William Bateson, a British zoologist (Darden, 1991). Bateson was soon to claim

[5] "My time will come" in German.

himself to be Mendel's chief apostle and it was he who first introduced Mendelism to the English-speaking world (Henig, 2000).

According to Darden's (1991) analysis, Mendel's segregation explanation that he used to account for his findings was progressively refined by Mendelians in the next 30 years during which many anomalies had been resolved. During the early 1900s, Mendelians did not distinguish between the laws of segregation and independent assortment. They used the segregation law to explain both the monohybrid and dihybrid crosses. It was only in the 1910s, after numerous resolutions of the anomalous 9:3:3:1 ratios, that independent assortment came to be known as a separate law. The two familiar laws of genetics (laws of segregation and independent assortment), named after Mendel, did not come into being until the 1920s. As Tudge (2000) summarised Mendel's ground-breaking work on explaining heredity, "he [Mendel] was a genius, able to see the simplicity that lies beneath the astonishing complexities of nature" (p. 109).

### 2.1.4 Bateson: Founder of Mendelism

In contrast to the three rediscoverers of Mendel's paper, Bateson saw the significance of Mendel's findings and the promise in Mendelism for developing a general theory of heredity (Darden, 1991).

According to Olby (1997), as Bateson's primary interest was in evolution, Mendel's segregation explanation—based on the purity and segregation of germ cells—provided him with a plausible explanation for non-blending variations in evolution. Like Mendel, Bateson "looked up to the physical sciences and prized the mathematisation of their science" (Olby, 1997, Section VI). Bateson extended Mendel's explanation of the observed modified ratios of 9:3:3:1 using the binomial equation. In 1911, he and his co-worker Punnett (famous for the Punnett square) introduced their *reduplication hypothesis* to mathematically explain the exceptions to the rule of the independent assortment of characters but this hypothesis was soon to be rejected when Thomas Morgan proposed his association hypothesis based on cytological evidence (see section 2.1.5).

Bateson was rightly called the founder of Mendelism (Bowler, 1989) but his contribution to theory change of the gene was limited. Despite the emergence of Weismann's germplasm theory in 1886 and Boveri-Sutton's chromosome theory in

1902, Bateson's conception of segregation concerned only the event of the whole cell but not part of the chromosome (Darden, 1991). Not only did he dislike Weismann's cytological speculation about the physical basis of inheritance, he also opposed the chromosome theory of heredity. Bateson used Mendel's terms *factor* to denote something later to be called *gene* (coined by his friend, a Dutch botanist, Wilhelm Johannsen in 1909) and *allelomorph* (subsequently abbreviated to *allele*) to denote the alternative characters or segregating pairs. However, he did not refer to a chromosome nor to part of a cell (Darden, 1991; Tudge, 2000). Thus, Bateson was successful in introducing the terminology of genetics but was unable to advance Mendelism to connect it to chemistry nor to cytology (Bowler, 1989; Olby, 1997). Nonetheless, when Bateson coined the term *genetics*[6] in 1905 and launched it at an international congress in the following year, a science called genetics came into being, particularly in the English-speaking world (Bowler, 1989).

### 2.1.5 Morgan, His Students and Their Fruit Fly Experiments

Thomas Morgan (1866-1945), an American geneticist, was singled out by Tudge (2000) to have made the most significant contribution to the development of Mendelian or classical genetics. Morgan, who was an early critic of both Mendelism and the Boveri-Sutton's chromosome theory of heredity between 1900 to 1910, soon emerged as a proponent and a major developer of both when he and his students worked on breeding experiments with fruit flies (*Drosophila melanogaster*) (Darden, 1991). Morgan's one-time colleague, Herman Müller (1890-1967), elucidated the mechanism and importance of genetic mutation (Tudge, 2000) which, in my opinion, connected Mendelism to molecular genetics of the 1950s.

According to Darden (1991), the diverse assessments of the chromosome theory of heredity by testing the generality of Mendel's segregation explanation during 1906 to 1910 did not provide sufficient evidence to convince Morgan that the chromosomes constitute the entire physical basis of heredity and that they carry preformed units that produce all the characters in an organism. For example, the anomaly of Cuénot's 2:1 ratio in mice experiments confused Morgan so much that he

[6] Although the term "genetic" (*genetische* in German) was first used in 1816 by Count E. Festetics (1764-1847), it was a different term because it had a pre-Mendelian meaning (Tudge, 2000).

made a hypothesis to deny the segregation explanation—the central claim of Mendelism. In 1915, Morgan, Sturtevant, Müller and Bridges (1915) published a book to argue for the possibility of "the chromosomes as the bearers of the Mendelian factors, it would be folly to close one's eyes to so patent a relation" (p. ix). However, it was not until the time when his fruitfully experiments had provided new evidence to assess the chromosome theory of heredity that Morgan was able to develop the theory of the gene (Morgan, 1926). His succinct statement about the theory of the gene in 1926 summarised his and his students' significant contributions to Mendelian genetics over two decades:

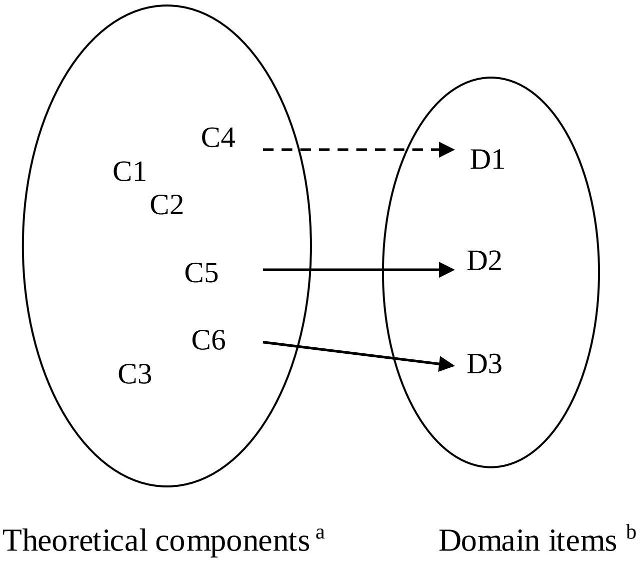
> The theory [of the gene] states that the characters of the individual are referable to paired elements (genes) in the germinal material that are held together in a definite number of linkage groups; it states that the members of each pair of genes separate when their germinal cells mature in accordance with Mendel's first law, and in consequence, each germ-cell comes to contain one set only; it states that the members belonging to different linage groups assort independently in accordance with Mendel's second law; it states that an orderly interchange—crossing over—also takes place, at times between the elements in corresponding linage groups; and it states that the frequency of crossing-over furnishes evidence of the linear order of the elements in each linkage group and of the relative position of the elements with respect to each other. (Morgan, 1926, p. 25)

### 2.1.6 Genetics Reasoning from 1900 to 1926: Some Patterns

Darden's (1991) overview of the thinking of the Mendelians during 1900 to 1926 indicated that there were three reasoning strategies—to produce new theories, to assess them and to improve them by anomaly resolutions—appeared to operate throughout the historical development of theories about Mendelism.

#### *2.1.6.1 Reasoning of Early Mendelians (1900-1903)*

Based on the historical evidence from the published work of de Vries, Correns, Castle, and Bateson, Darden (1991) described the relations between the domain and the theoretical components of Mendelism involved in the reasoning of the geneticists during the period 1900 to 1903. I have redrawn the diagram (see Figure 2.1) to map the theoretical components to the items in the domain of Mendelian genetics. The theoretical components can be regarded as the domain-general heuristics and the domain items are empirical observations within or across generations so that such mapping can be compared to the two-dimensional genetics reasoning types (Hickey & Kindfield, 1999) (see Chapter 3, Table 3.1[7]), which I will use in interpreting student learning in the following results chapters in this thesis.




LEGEND

| [a] Theoretical components: | | [b] Domain items: | |
|---|---|---|---|
| C1 | Unit-character | D1 | Dominance |
| C2 | Pairing | D2 | 3:1 ratios (monohybrid cross F2) |
| C3 | Interfield relation: germ cells | D3 | 9:3:3:1 ratios (dihybrid cross F2) |
| C4 | Dominance-recessiveness | ——→ | explains |
| C5 | Segregation | - - - → | promissory note |
| C6 | (Independent assortment) | | |

*Figure 2.1* Mapping early Mendelians' (1900-1903) theoretical components to domain items in explaining inheritance (adapted from Darden, 1991, p. 62, Figure 5.1).

According to Darden (1991), the theoretical components C1 to C3 were not direct explanations of the domain items. C5 and C6 explained the two domain items D2 and D3 but component C6 (independent assortment) was not explicitly used

[7] Thereafter in the thesis, only the table or figure number such as Table 3.1 is used in cross-chapter references. For example, Table 3.1 refers to Table 3.1 in Chapter 3 and can be located using the page number given in the List of Tables.

during the period 1900-1903 and that C4 was metaphorically considered as "a promissory note" (p. 63) in providing an explanation for D1. Other components C1 to C3 were related to C5 and C6 to different extent and their relative positions in the diagram indicate roughly the relevance and connectedness of their relationships to C5 to C6 (see Figure 2.1).

During 1900-1903, the only change in the theoretical components was C5 or *segregation* (see Figure 2.1). It was soon to be broken down into three components: *purity of the gametes* (separation of factors into different types of pure germ cells), *equal numbers* (equal number of the types of germs cells) and *random combination* (random combination of the types of germ cells at fertilisation) (not shown in Figure 2.1 for clarity's sake). As Darden (1991) pointed out, Mendelism continued to develop during 1900 to 1910, because the theoretical components purity of the gametes and random combination were challenged by anomalies but had survived the tests while equal numbers, the central core of the segregation explanation, remained unchallenged. This will be discussed further in the next sections. As we shall see, most of the theoretical components in Figure 2.1 were to change to parallel the corresponding changes in the domain items for resolving anomalies in the years leading to 1926.

#### *2.1.6.2 Reasoning Strategies in Theory Change of the Gene*

The domain of Mendelian genetics in the early 1900s had a rather limited scope. From 1903 to 1926, as a result of numerous studies and anomaly resolutions, the theoretical components were changed by the strategies of *generalising*, *specialising*, *complicating*, *adding* and *deleting* to resolve the anomalies and to expand the scope of the domain (Darden, 1991; 1992). During the early 1900s, the change of theoretical component C5 *segregation*—(see Figure 2.1) to *purity of gametes*, *equal numbers* and *random combination* (not shown in Figure 2.1 for clarity's sake) mentioned in the preceding section—was an example of theory change by these reasoning strategies.

The next to change was the theoretical component C1 or *unit-character* (see Figure 2.1) originally used to mean the characters or the germ cells that brought about the characters rather than some units carried by the germ cells. In 1906, geneticists such as Bateson and Punnett began to discuss about numbers and the factors differently from the characters they controlled by *generalising* this theoretical component to units carried by germ cells. This generalised theoretical component that one factor produces one character was very important as this was used to explain the simple cases of 3:1 and 9:3:3:1 ratios. This can be later *specialised* and *complicated* to explain more complex factor combinations such as the anomalous ratio of 15:1 in wheat kernel colours (Russell, 2002). A related new domain item D4 for anomalous 9:3:3:1 ratios was to be *added* to the model in Figure 2.1 (not shown). As the research of Morgan's *Drosophila* group provided more evidence, the theoretical component C2 (one-one pairing) was complicated and specialised into new components. For example, Mendel's *differentiated pairs of characters* was first changed to Bateson's *unit characters* or *allelomorphs* and then to Morgan's alleles at the same locus of homologous chromosomes. Then, a new component of multiple alleles occurring in populations was proposed by Morgan (1926).

Such modification of the gene theory increased the explanatory power by expanding the scope of the domain of Mendelian genetics which can provide a universal explanation for all phenomena of genetics and a particulate basis for the molecular genetics (Darden, 1991). As the development of theory progressed, the theoretical component C4 (dominance-recessiveness) (see Figure 2.1) was *deleted* because although it was a promissory note for explaining domain item D1, it had been found to lack the *explanatory adequacy* over the years. It was no longer a useful theoretical component. As a result of the change in C4, there was also a corresponding bifurcation of the domain (see Figure 2.1) into two sets: some characters were produced by one factor and others by multiple factors. For example, the domain item D1 (dominance), which was originally considered as an empirical generalisation, was no longer useful as there were many exceptions to dominance. D1 was then *specialised* to D1.1 (dominance) (not shown in Figure 2.1), a form of dominance in the light of exceptions, and *complicated* to two new items, D1.2 (incomplete dominance) and D1.3 (a new form). No theoretical component had such explanatory power for predicting whether a heterozygote (hybrid) would show which dominant pattern before the empirical determination was made. In the light of modern genetics, this entails embryological development and gene expression which were beyond the thinking of the early Mendelians.

From 1900 to about 1926, the theory of the Mendelian gene had undergone a number of further changes in both the theoretical components and the domain items.

The major reasoning strategies, the changes and the results are summarised in Table 2.2.

Table 2.2

*Summary of Major Strategies for Changing the Theory of the Gene from 1900 to 1926 (based on Table 14.2 Darden, 1991, p. 241)*

| Reasoning Strategies | Theory Changes[a] | Results |
| --- | --- | --- |
| Conceptual clarification | Unit-character (C1) →[b] genes causes characters | Postulation of theoretical entities |
| Complication, specialisation and addition | One-one (C1, C2)→ one-many, many-one, or many-many | Expanded scope of domain; addition of new theoretical components |
| Postulation of interfiled relations | Explicit identification of germ cells (C3) | Other concept and levels available for use in other components |
| Deletion | Deleting dominance component with many exceptions (C4) | Overgeneralisation removed; expanded scope of domain |
| Make separable assumptions explicit; (possibly) deny and propose opposite | Purity and segregation (C5):<br>together → separate | Newly delineated components and (possibly) alternative hypothesis ready for testing |
| Delineate and alter | Separate the law of independent assortment from the law of segregation (C5, C6) | One law separated into two and significant new components added to theory limiting the generality of the second law and resolving model anomalies |
| Specialize and add use | The law of independent assortment specialized to apply to genes in different linkage groups (C6) | |
| Interrelations and analog to generate new ideas | Addition of new components of linkage, crossing-over and linearity (C6) | |
| Add new component by quantitatively altering old idea | De Vries mutation → smaller scale mutations (C7 [c]) | Addition of new component to theory (new research program) and expanded scope of domain |

[a] C1 to C 6 refer to the original theoretical components in Figure 2.1 originally conceptualised by early Mendelians but successively refined by resolving anomalies over the years.

[b] The arrow indicates a change with the strategies given in the second column.

[c] C7 is a new added theoretical component in the late 1910s as a result Morgan and his students' work on the mutations in fruit flies.

### *2.1.6.3 Anomaly Resolution: Two Examples*

To illustrate the strategies used in anomaly resolution during 1900 to 1910, Darden (1991) used a number of examples. Two successful examples are given here: Castle and Little's resolution of the anomalous 3:1 ratios and Morgan's resolution of the anomalous 9:3:3:1 ratios.

In resolving the anomaly of Cuénot's 2:1 ratio in 1905 (Russell, 2002), the first strategy was to *reproduce the anomalous data*. Then, one had to *localise the anomaly*, that is, to localise the theoretical component for explaining the domain for which the anomaly has been found. In this case, the theoretical component is C5 or segregation in Figure 2.1. Historically, Morgan, Cuénot, and Castle (and Little), who had each generated *an alternative hypothesis* to explain this anomaly, focused on different theoretical components associated with the Mendel's segregation explanation. Unlike Morgan who focused on altering the purity component and Cuénot who focused on altering the random component (see section 2.1.6.1), Castle and Little focused on uncovering an implicit assumption of equal viability of fertilised eggs that did not entail additional component for the explanation. The fourth strategy was to *test the alternative hypothesis.* In this particular example, Castle and Little's inviability hypothesis that homozygous dominant yellow rats were aborted in utero (Russell, 2002) was tested to be correct because it fit the empirical evidence from the dissection of dead embryos. The successful resolution of this anomaly resulted in adding a condition of homozygous lethals to the theoretical component C5 (see Figure 2.1).

The second historical example was Morgan's successful resolution of the anomalous 9:3:3:1 ratios that resulted in considerable change in the theoretical components (C5 and C6 in Figure 2.1). In the 1910s, the progress made by Morgan's *Drosophila* group led him to the hypothesis of the *association of factors* that provided a plausible explanation of the anomalous 9:3:3:1 ratios, such as 9:7 or 15:1, which Bateson and Punnett were unable to explain using their hypotheses of *coupling* and *reduplication*. Morgan said in 1911 (cited in Darden, 1991), "Instead of random segregation in Mendel's sense we find 'association factors' that are located near together in the chromosomes. Cytology furnishes the mechanism that the experimental evidence demands." (p. 135). Although de Vries and Boveri suggested much earlier that *pangens* (genes) could jump between nuclear threads, it was Morgan who, using both breeding and cytological data, associated factors (genes) for red and white eyes in fruit flies to a specific chromosome, the X chromosome.

Like Castle and Little, Morgan used most of the general strategies to resolve anomalies. For example, he *generated an alternative hypothesis* (association of factors) by *delineating and altering* the laws of segregation and independent assortment, *specialising* the law of independent assortments and *adding* a condition for some genes not assorting independently because of *linkage* and *crossing-over*. Morgan also used *interrelations* between two bodies of knowledge, namely, Mendelian genetics and cytology; and *postulated a new level of organisation*, namely, linkage groups for associated genes on a chromosome. As Darden (1991) put it, the use of these two general reasoning strategies—interrelations and a new level of organization—was crucial to the success of Morgan in producing the new ideas of linkage and crossing-over. More findings from the *Drosophila* experiments of Morgan, his co-workers and students—Bridges (1889-1938), Müller's (1890-1967), and Sturtevant (1891-1970)—on linkage, crossing-over and mutation soon provided new empirical evidence to support Morgan's hypothesis. The theoretical component C6 in Figure 2.1 was specialised into new components of linkage and crossing-over (also see Table 2.2). *Mutation* was then added as a new theoretical component C7 (see Table 2.2). It also necessitated the corresponding addition of new domain items about linkage, crossing-over and mutation. With his chromosome theory of the gene based on his *Drosophila* research, Morgan successfully resolved the anomalies about independent assortment and brought classical genetics to fruition in the 1920s.

To summarise this section, both Castle and Little's and Morgan's alternative hypotheses were accepted because they satisfied most of the criteria for assessing alternative hypothesis: *explanatory adequacy*, *predictive adequacy*, *lack of ad hocness*, the *generality of the scope* of the domain items covered by the hypotheses, *simplicity, extendability and fruitfulness* (Darden, 1991). Darden's ideas are based on other authors' work including Thagard's (1988) computational philosophy of science (see section 3 in this chapter).

### 2.1.7 Representations as Vehicles for Reasoning

As can be seen the in the preceding sections, by resolving the empirical anomalies and then changing or adding the theoretical components, geneticists were able to expand the scope of the domain of genetics. According to Darden (1991), in moving from an empirical level to a conceptual level as geneticist developed the gene theory, symbolic representations for the theoretical entities and conceptual manipulation of these representations appeared to play an important role in explaining the empirical data. Analogies, metaphors, diagrams and images were such representations that served as vehicles for reasoning.

In the 1860s, Mendel (1865a) used linguistic entities in German, such as *Merkele* (character), *Elemente* (factors) and symbols, such as *A 2Aa a* as tools in his reasoning (see Figure 2.2). He then manipulated the symbols to explain and predict the dihybrid cross by combining the expressions *(A + 2Aa + a)* and *(B + 2Bb + b)* to *AB + Ab + aB + ab + 2ABb + 2aBb + 2AaB + 2Aab + 4AaBb* or the *9:3:3:1* ratio as later interpreted by Mendelians (see section 2.1.2).

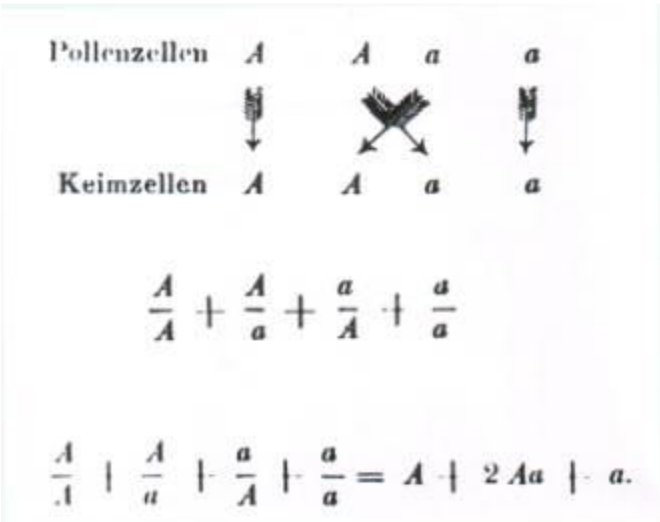



*Figure 2.2* Mendel's diagrams for hybrid cross. From Mendel's (1865) original paper *Versuche über Pflanzen-Hybriden,* p. 30 (cited in Darden, 1991, p. 173). (*Pollenzellen* and *Keimzellen* are pollen cells and germinal cell in German.)

In the 1910s, Punnett made a theoretical diagram to illustrate the *reduplication hypothesis* (see Figure 2.3) which Bateson and he proposed to explain the anomalous 9:3:3:1 ratios but this was not supported by cytological evidence. Punnett's tabular representation (see section 2.3.3.1) or the *Punnett square* was, and still is, the most familiar checkerboard algorithm for working out the Mendelian ratios (Henig, 2000).

Morgan and his students used new terminology for the entities based on a hypothetical analog model, such as *crossing-over* despite that cytological evidence for crossing-over was only observed in the 1930s. They also used diagrams to show the hypothetical model of *beads-on-a-string* in 1915 (see Figure 2.4) and drawings to illustrate sex linkage in 1926 (see Figure 2.5).

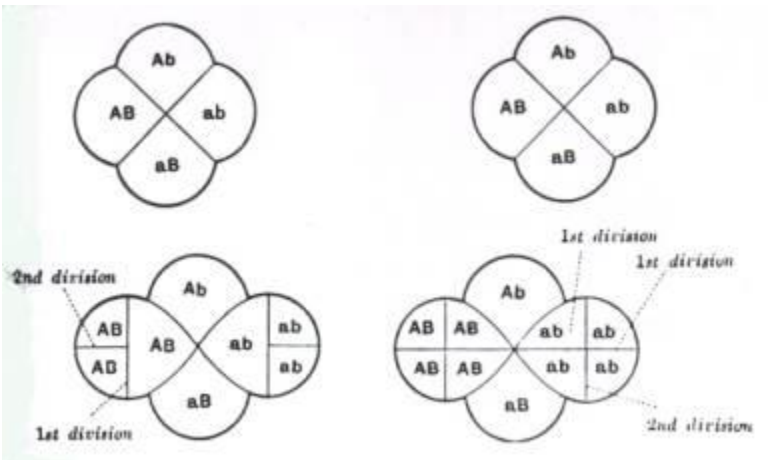



*Figure 2.3* Punnett's reduplication diagrams in 1913 (From Punnett, 1913 cited in Darden, 1991, p. 125).

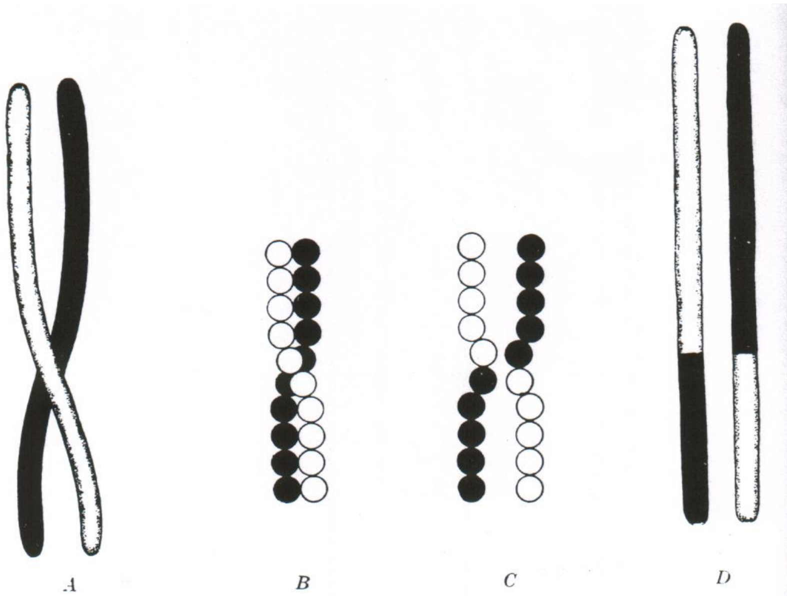



*Figure 2.4* Diagrams representing crossing-over (adapted from Morgan et al., 1915, Figure 24, p. 60).

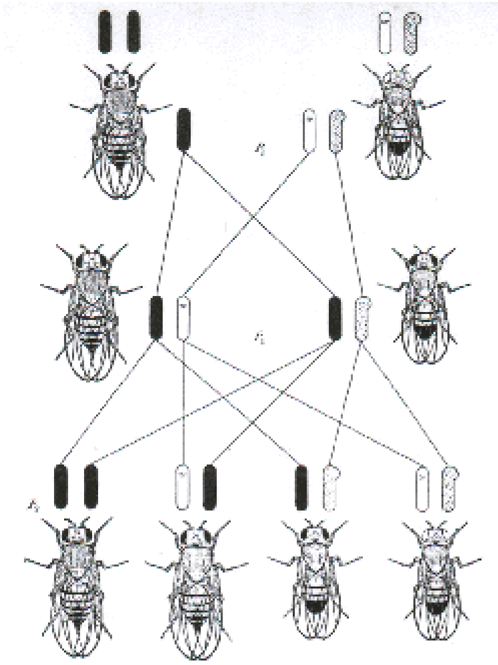


*Figure 2.5* Morgan's illustration of sex linkage (Morgan, 1926, p. 60).

As Cock (cited in Darden, 1991) put it, "[t]hroughout most of the first decade of the century the chromosome theory of heredity had no more support than a simple, if impressive, analogy" (p. 93). As the development in cytology progressed, the early Mendelians noticed the similar properties and behaviours of the chromosomes and Mendelian factors. Such observations allowed them to use analogical reasoning (see section 2.3.1) to develop the gene theory in terms the chromosome theory.

Morgan's analog model—based on visual image of chromosomes—was a powerful vehicle for reasoning. It is more fruitful than the analogical reasoning which Bateson used by referring to some entities from the domain of physics, such as *coupling*. As Darden (1991) put it, the analog model had three useful functions: (1) it provided terminology for a hypothesis; (2) it served to resolve anomalies that arose for the hypothesis; and (3) it supplied theoretical language for the new hypotheses that explain the anomalies. For example, Boyd (cited in Darden, 1991) used "theory-constitutive metaphors" (p. 164) to describe the role played by Morgan's analog model of *beads-on-a-string* based on which the new entities such as *crossing-over* were constructed. Accordingly, the model of beads-on-a-string soon became a public metaphor for genes being arranged linearly along the chromosome. This metaphor is useful even today as a visual-graphical representation (see the third part in this chapter) in explaining genetics in textbooks and multimedia programs such as *BioLogica* software used in this research. Nonetheless, this metaphor is a poor representation of the sophisticated conception of a gene (see section 2.2.9.1).

The history of genetics reasoning from Mendel to Morgan illustrates the role played by analogies, metaphors, diagrams and images as being vehicles for reasoning not only in the initial production of the theory of the gene but also in its subsequent development through endless anomaly resolutions, modifications and refinement through manipulation of these representations in explanations and predictions.

### 2.1.8 DNA Double Helix Model and Modern Biology

The years from 1926 to 1953 saw the transition of the science of genetics from Mendelian genetics to molecular genetics. Watson and Crick's (1953b) double helix model of deoxyribonucleic acid (DNA) provided an adequate mechanism that not only explains how the genetic information can be replicated and passed to the offspring when the cell divides but also how the gene controls protein synthesis.

Thagard (1992b) argued that Watson and Crick's model was not one of the conceptual revolutions in science as the model "primarily added part-relations rather than revising previously established ones. The advent of molecular biology did not require any noticeable abandonments of theory, evidence, or method" (p. 154). Nevertheless, Watson and Crick's Nobel-winning double helix model of the DNA in 1953 revolutionised the life sciences in the 50 years that followed. In addition to using Darden's (1991) theory change model, I am using Giere's (1991) cognitive method in analysing Watson and Crick's reasoning leading to the major breakthrough in molecular genetics.

#### *2.1.8.1 Genetic Material: Proteins or DNA*

From Morgan's (1926) theory of the gene, it was known that genes are on chromosomes, those thread-like structures in the cell nuclei that contain both nucleic acids and proteins, but little was known about the nature of the gene. As earlier as 1928, Griffith discovered the genetic transformation of bacteria and called the agent responsible the *transforming principle* but believed that it was a protein (Russell, 2002). Although in the 1940s Avery and his colleagues clearly showed that the Griffith's transforming principle was deoxyribonucleic acid (DNA), most biologists in the 1950s still thought that genes are made of proteins instead of DNA (Giere, 1991; Russell, 2002).

It was in 1950 that a 22-year-old *wunderkind* biologist, James Watson, had just completed his PhD in Indiana University of the USA, under Salvador Luria, a wartime geneticist whose research area was on bacteriophages. Like Luria, Watson thought that the structure of DNA was the key to understanding modern biology. In the same year, while unhappily working in biochemistry as a post-doctoral fellow in Copenhagen, Watson attended a meeting of scientists in Italy. There, he was excited by a presentation of Maurice Wilkins from King's College (England) who talked about an X-ray diffraction photograph of DNA. Back in Copenhagen, he read more about the X-ray method. The then recent work of the famous physical chemist Linus Pauling on alpha-helix structure of proteins using the X-ray data greatly inspired Watson. He saw the promise of using the X-ray method to study DNA structure so much that he decided to go England in search of the secret of life (Giere, 1991) .

#### *2.1.8.2 DNA Brought Watson and Crick Together*

In 1952, Watson started to work in the Cavendish Laboratory in Cambridge (England) to learn about using X-ray techniques in molecular biology research. It was there that he met Francis Crick who was still doing his PhD. They soon collaborated in their work as they both were interested in DNA structure and believed in its possible helical structure (Giere, 1991). Watson (1968) later recounted his first experience in Cambridge:

> From my first day in the lab I know I would not leave Cambridge for a long time. Departing would be idiocy, for I had immediately discovered the fun of talking to Francis Crick. Finding someone in Max's lab who knew that DNA was more important than proteins was real luck. (p. 46)

Watson and Crick's collaboration soon beat a world-renowned physical chemist Pauling by a matter of months or even weeks in proposing the DNA model which was, in Watson's (2001) own words, "the culmination of almost a century of genetics"(p. 20).

#### *2.1.8.3 The Race to Find the DNA Structure*

In the 1950s, as Watson (2001) later recollected, England was still backward in terms of the research in genetics. The Cavendish Laboratory under Sir Lawrence Bragg, who shared a Nobel Prize with his father in 1915 for their discovery of the X-ray crystallography, was a key centre for research of molecular structure of life substances.

While in England in 1951, Watson got to know Wilkins and his co-worker Rosalind Franklin who also were trying to find the DNA structure. Franklin's X-ray data soon turned out to be crucial for Watson and Crick's double helix model of the DNA. While Watson focused on building a model, Crick soon developed a theoretical account of helically shaped molecules as depicted by X-ray photographs. In November 1952, Franklin presented her work on X-ray photographs of DNA in London. After Watson and Crick had attended Franklin's presentation, they became excited as they thought they could build a model of DNA. In December 1952, they invited Wilkins and Franklin to Cambridge to see their three-chain DNA model which they had built. Franklin quickly pointed out the major flaw of their model (Giere, 1991; Russell, 2002; Watson, 1968).

Humiliated by Franklin and banned from further model building by Bragg, Watson and Crick began to think about a two-chain model. While Watson learnt more about X-ray techniques with picturing the tobacco mosaic virus (TMV), new evidence about DNA from the USA in 1952—Chargaff's findings about the unity ratio of the base pairs (adenine-thymine or A-T and cytosine-guanine or C-G)—provided more hints for Watson and Crick to build a model that works. As Watson and Crick knew that Pauling in the USA was also finding the DNA structure but still grappling with the same flawed triple helix model, they understood that they needed to race with time (in less than 6 weeks) to build their DNA model before Pauling improved his (Giere, 1991; Russell, 2002; Watson, 1968). In a recent biographical writing about Alfred Hershey (1908-1997), Watson (2001) reflected that Hershley and Chase's successful experiment in 1952—which showed that the genetic material of bacteriophage T2 is DNA—had a strong impact on him and Crick in building the double helix model of DNA in 1953:

> The Hershey-Chase's experiment had a much stronger impact than most confirmatory announcements and made me ever more certain that finding the three-dimensional structure of DNA was biology's next most important objective. The finding of the double helix by Francis Crick and me came only 11 months after my receipt of a long Hershey letter describing his blender experiment results. (Watson, 2001, p. 41)

In January 1953, when Watson went to London to see Franklin and Wilkins, he was given more X-ray photographs including a crucial photograph of the B-form of DNA. Back to Cambridge, Watson and Crick built a two-chain scaled model with cut out cardboard and metal plates. Wilkins and Franklin soon agreed that Watson and Crick's proposed double helix had been confirmed by their X-ray data. With the support of Bragg, and positive feedback from Wilkins and Franklin, Watson and Crick (1953b) published their proposed double helix model of DNA in *Nature* on April 25, 1953. By prior arrangement, Wilkins and Franklin also had each a paper on X-ray method in the same issue of *Nature* (Giere, 1991; Watson, 1968).

The double helix model of the DNA has survived theory assessments by numerous researchers related to the science of genetics using Darden's (1991) criteria, namely, explanatory adequacy, predictive adequacy, lack of ad hocness, the generality of the scope, simplicity, extendability and fruitfulness. In the decade that followed, the DNA model had greatly advanced the biomedical research. In 1962, Watson, Crick and Wilkins were awarded the Nobel Prize for medicine or physiology for their contribution. As Watson (1968) later wrote, Rosalind Franklin, who unfortunately died of cancer in 1958, should have been a co-winner of the Nobel (never awarded posthumously) because the crucial contribution of her X-ray data to building the double helix model in 1953. Over the decades since 1972 when Berg created the first recombinant DNA molecule on the lambda phage, genetic engineering, genetically modified organisms including food crops, cloning and genomics[8] have the most remarkable impact on human life (Russell, 2002).

It is still a legend in the history of biology that only during a very short time from 1951 to 1953 were Watson and Crick able to build their double helix model of the DNA that has revolutionised modern biology in ways no one in the 1950s could have imaged. How did Watson and Crick reason along the track leading to the

[8] Genomics is "[t]he development and application of new mapping, sequencing, and computational procedures to analyse the entire genome of organism" (Russell, 2002, p. 734).

building of the double helix model? That is the question to be answered in the following sections.

#### *2.1.8.4 Reasoning Trajectory of Watson and Crick*

In May 1953, Watson and Crick's (1953b) short breaking-news article in *Nature* began with "We wish to suggest a structure for the salt of deoxyribose nucleic acid (D. N. A.). This structure has novel features which are of considerable biological interest" (p. 737). One month later, they published another short article (Watson & Crick, 1953a) about the "genetical implications" (p. 964) of the double helix model of DNA.

To argue for their case, they put forward several points of empirical evidence from previous research to argue in favour of their double helix model despite that "[t]he previously published X-ray data on deoxyribose nucleic acid are insufficient for a rigorous test of our structure.": (1) Pauling's 3-chain helical model was unsatisfactory (as was their previous similar conception); (2) the structure (with sugar-phosphate backbone on the outside) allowed for its high water content as indicated by empirical data; (3) base pairing holding two chain together matched Chargaff's unity ratio of two pairs of nucleotide bases; and (4) the structure (double helical) was roughly compatible with X-ray data (supported by unpublished data of Wilkins and Franklin); and (5) specific base pairing suggests a possible copying mechanism for the genetic material.

Whereas Darden (1991), who actually referred to Giere's (1984) work (p. 161), used explanatory adequacy and predictive adequacy for the assessment an alternative hypothesis, Giere (1991) similarly used the criteria of whether the DNA model fits the real world situation and whether the model can make predictions. The double helix soon became the basic model for the development of the theory of molecular biology. According to Giere's (1991) analysis, the case of Watson and Crick's double helix model of DNA of 1953 illustrated how the four basic elements—*model, real world*, *prediction* and *data*—interacted in the evaluation of whether the proposed model adequately represented the real world or the structure and function of the gene or DNA. As Giere (1991) pointed out, one worry for evaluation of scientific model or hypothesis is that non-specialists always have to depend on the reported judgements of specialists for accepting an alternative hypothesis. The following simplified process for evaluating Watson and Crick's double helix model of the DNA is partly based on Giere's (1991) and Darden's (1991) ideas (also see Figure 2.6):

Step 1: Identification of the DNA structure being an important aspect in biological science (real world) and the unknown information about the DNA.

Step 2: Construction of a theoretical model to represent the DNA.

Step 3: Identification of data already obtained by observation or experiments. Check if the model fits the real world. If it fits, go to Steps 4 and 5 or if not, repeat Step 3.

Step 4: Identification of a prediction based on the model

Step 5: Evaluation of whether the data agree with the prediction; if not, the model, does not fit the real world i.e., the model is rejected.

Step 6: Evaluation of whether the data agree with the prediction; if yes go to Step 7 or if not, the model needs revision

Step 7: Check whether the data fit prediction if the model does not fit the real world; if yes, then the model the data is inconclusive regarding the fit between the model and the real world or if not, the model does fit the real world.

However, it is not often easy for non-specialists to evaluate the model or the theoretical hypothesis. In the case of the double helix model, one has to know physical and organic chemistry well in order to evaluate whether the model was likely to fit the real world (see Figure 2.6).

Although we may agree with Thagard's idea that Watson and Crick's DNA model should not be considered as a conceptual revolution, we should consider Watson and Crick's contribution as the most important revolution in biological sciences in the 20$^{th}$ century. The double-helix model of DNA unquestionably revolutionised our understanding of all aspects of the life sciences. Watson and Crick's model can be used, as Morange (2001) put it, "to explain the fundamental phenomena of life through the properties of its macromolecules."(p. 16). Watson and Crick's model explains both the mechanism of the self-replication of DNA or a gene and the protein synthesis which DNA or a gene controls.

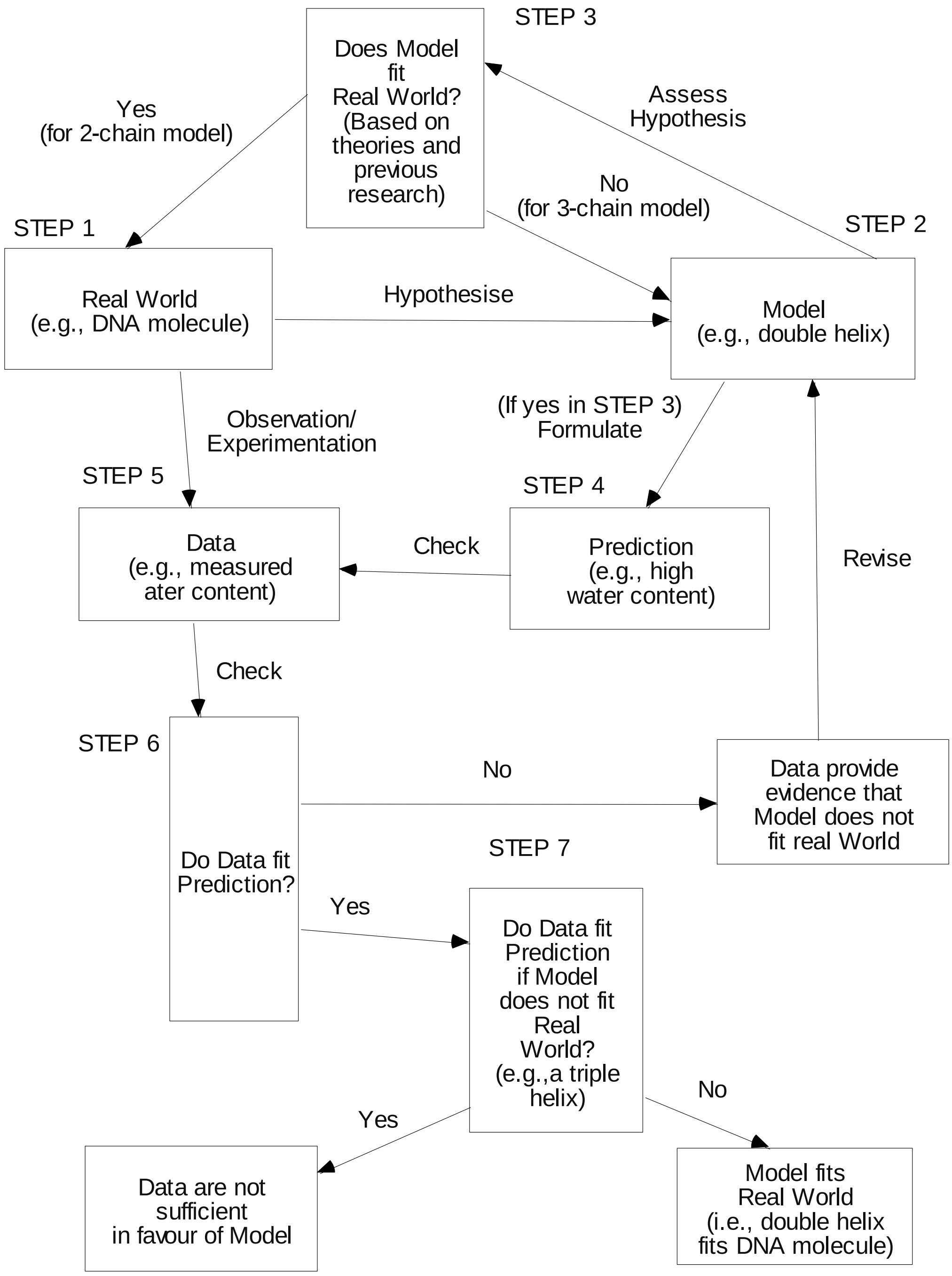



*Figure 2.6* Flow chart showing Watson and Crick's reasoning trajectory in their discovery of the DNA model (partly based on Giere, 1991).

In February 2003, *Time* magazine published a special issue to commemorate the golden anniversary of the discovery of the DNA structure. As Time's Lemonick

(2003) commented, Watson and Crick—inexperienced scientists with nonexistent track records—had “a fair amount of luck” (p. 43) when they solved the mystery of life in 1953 before anyone one else. When interviewed by Lemonick (2003), Watson asserted that he and Crick deserved the discovery of the DNA structure for the following reasons: (1) they thought it was the most important problem, (2) they believed in solving the problem by building models, (3) “they had each other” (p. 46) in collaboration to solve the problem, (4) they were willing to ask for help and talk to their competitors, (5) “you have to be obsessive” (p. 46), and (6) they could take a chance to solve the problem because they knew they would have careers even if they failed.

Perhaps these new comments of Watson about their discovery of the double-helix may provide some food for thought when discussing the critique of the metaphor of *student as scientist* (Pintrich, Marx, & Boyle, 1993) and intentional learning of students later in this chapter.

### 2.1.9 Teaching and Learning of Genetics in Schools

In the first part of this chapter, I have reviewed how scientists from Mendel to Watson and Crick reasoned in making progress in the science of genetics. Most of today’s schools include the teaching and learning of science and genetics is likely to be taught at some stage during secondary school education.

Over the past two decades, researchers in Australia, New Zealand, the UK and the USA have unanimously found that genetics remains linguistically and conceptually difficult to teach and learn in secondary schools (see for example, Bahar et al., 1999; Hackling & Treagust, 1984; Johnstone & Mahmoud, 1980; Longden, 1982; Stewart, 1982; Venville & Treagust, 1998; Wood, 1993, 1996). Yet genetics has now become a central component of school biology and is essential for understanding some important contemporary issues such as genetically modified foods, genomics and cloning. One reason why concepts of genetics are particularly difficult to learn is that learning genetics requires multilevel thinking (Johnstone, 1991)—an organism is at the *macro level*, cells, chromosomes or DNA are at the *micro/submicro level*, and genotypes are at the *symbolic level*, which I have depicted using Johnstone’s idea in Figure 2.7. Besides the multilevel nature of genetics knowledge, the use of terminology of genetics, such as the use and misuse of synonyms, obsolete or redundant terms (see for example Pearson & Hughes, 1988a) has accentuated the difficulties of learners.

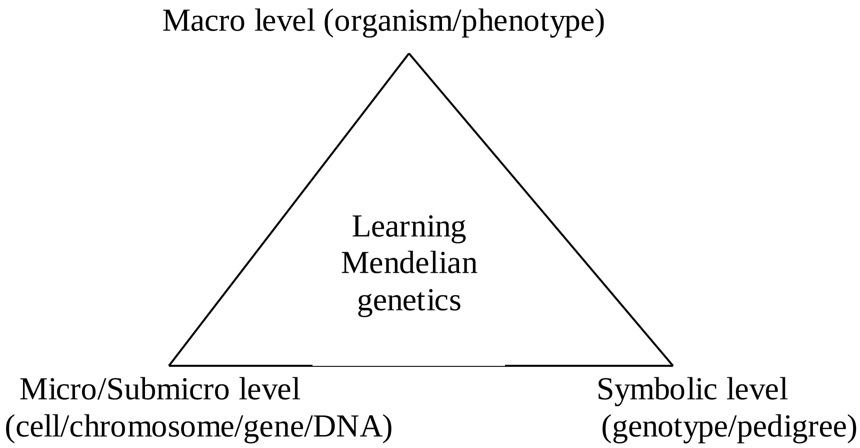



*Figure 2.7* Model of multilevel thinking in Mendelian genetics adapted from Johnstone (1991).

The conceptual learning perspective is now generally used for understanding and improving science education. Of relevance to this study is that conceptual change is a necessary precondition for scientific reasoning and successful scientific problem solving (Spada, 1994). This perspective asserts that a concept has to be built upon students' prior ideas about that concept and that the learning process has to be embedded in supporting conditions including "motivation, interests and beliefs of learners and teachers as well as classroom climate and power structures" (Duit & Treagust, 1998, p. 15). However, as will be discussed in the next section, in order for students to benefit more in school learning of science, science educators need to rethink about the traditional conceptual change model.

## 2.2 Learning as Conceptual Change

In 1957, the launching of the USSR's satellite *Sputnik* sparked a series of reforms in science education in Western countries, first in the USA, and then in England. Similar reforms soon began in France, Germany, Sweden, Canada and Australia (Bliss, 1995). The national Australian Science Education Project (ASEP) in 1969-1975 aimed at lower secondary science was one of such reforms during that period (Rennie, Fraser, & Treagust, 1999).

According to de Jong et al.'s (1998) extensive literature review, three paradigms dominate today's field of learning and instruction. The first one is *constructivism* which asserts that students should be encouraged to construct their own knowledge instead copying it from authority (textbooks or teachers). The second one can be called *situationism* which simply means that students need to learn in realistic situations instead of in those decontextualised, formalised situation such as the classroom. The third is *collaborative learning,* which is about students learning together with others instead of on their own. In science education, conceptual learning model (CCM) (Posner et al., 1982) (thereafter referred to as CCM) and the related models advanced from it, have proved to be useful for interpreting student learning for understanding. In this research, I used Tyson et al. (1997) multidimensional CCM, which, I believe, has synthesised the aforementioned three paradigms of de Jong et al. in one way or another.

### 2.2.1 Piaget, Constructivism and Conceptual Change

Piagetian ideas had a direct influence on the science education reforms in the 1960s. Piaget was also one of the first proponents of constructivism, the various forms of which soon came to bear on the direction of science education in the Western countries in the decades that followed. A common core for conceptual change learning and instruction in science education has been the constructivist approaches which share "a view of human knowledge as a process of personal cognitive construction, or invention, undertaken by an individual, for whatever purpose, to make sense of her social or natural environment" (Taylor, 1993, p. 268).

Although constructivist approaches appeared to be a common core for conceptual change learning and instruction in science education (Duit, 1999), there are many variants of constructivist views (Duit & Treagust, 1998; Matthews, 1998; Taylor, 1998; Tobin, 1990). In the 1990s, new perspectives came into being, for example, Linder (cited in Duit, 1999) discussed a constructivist perspective of conceptual change that views conceptions as mental representations and a phenomenographic perspective that depicts conceptions as being the learner's different person-world relationships based on his or her experiences. Linder's critique of the constructivist approach to conceptual change brought to the fore the issue of the significance of context in specific conceptions. Similar views were soon to emerge in the form of social constructivist, sociocultural, and situated learning perspectives (Driver et al., 1994; Lave & Wenger, 1991; Morgan, 1926; Werstch, 1985). Science educators soon began to see the limitations of Piaget's ideas about learning science, in particular, his stage theory, and his general operational schemes (Bliss, 1995; Driver et al., 1994) or the content-independent logical operations (Vosniadou, 1999). Since Vygotsky's (1962; 1978) work was translated into English, his perspective—particularly his notion of the *zone of proximal development* and mediating action of *language as a tool* on thinking—also have gradually had an appeal for science educators as a more useful framework than Piagetian learning theories (Hodson & Hodson, 1998).

According to Duit and Treagust (1998), one early challenge of Piaget's generic cognitive structure and Piagetian stages came from Novak (1978) and his interpretation of the Ausubel's (1968) theory of meaningful reception learning. Novak's (1978; 1998; Novak & Gowin, 1984) notion of hierarchically-organised cognitive structure of concepts in the form of concept maps has since become one of the most popular pedagogical and research strategies in science education (see for example, Markham, Mintzes, & Jones, 1994; Morgan, 1926; Novak, 1990; Pankratius, 1990; Ruiz-Primo & Shavelson, 1996; Rye & Rubba, 1998; Stewart, van Kirk, & Rowell, 1979; Wallace & Mintzes, 1990).

### 2.2.2 Ausubel's Assimilation Theory of Learning

A brief review of Ausubel's assimilation theory of learning in this section provides a theoretical framework for analysing student interview data using concept mapping technique (Novak, 1998) in Case Study One (see Chapter 4) and teachers' instructional strategies in other results chapters in this thesis.

As reviewed by Novak (1978), Piaget's assimilation and accommodation, and Ausubel's subsumption and integrative reconciliation are perhaps the most influential. Unlike Piaget's description of assimilation and accommodation, which was based on the stage-like cognitive structure, Ausubel's description of these phenomena was in terms of the role that specific concepts or propositions play. However, both Piaget and Ausubel agreed that learning interacts with the learner's previous experience. Ausubel's (1968) famous dictum best summarises this idea: "If I had to reduce all the educational psychology to just one principle, I would say this:

The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly (p. vi).” The difference appears to lie in how to teach the learner accordingly.

Ausubel’s (1968) assimilation theory of learning was once proposed by Novak (1978) to be an alternative to Piagetian psychology for science and mathematics education. The assimilation theory consists of seven major components: *meaningful learning, subsumption, obliterative subsumption, progressive differentiation, superordinate learning, integrative reconciliation, and advance organisers* (see Novak, 1998). Ausubel (1968) distinguished meaningful learning from rote learning by two distinctive characteristics: “the nonarbitrariness and the substantiveness of the learning task’s relatability to cognitive structure”(p. 58). In meaningful learning, new concepts can be related, by nonarbitrary ways, to the previously established concepts. At the same time, substantive or nonverbatim nature of the learning, which relates to a new concept and incorporates it within cognitive structure, “circumvents the drastic limitations imposed by the short item and time span of rote memory on the processing and storing information” (p. 59). It must be noted that the term *meaningful learning* has since been widely used in educational contexts without always doing justice to Ausubel’s original definition.

### 2.2.3 Concepts, Representations, and Conceptions

When Posner et al. (1982) first proposed the CCM, they did not distinguish between *concepts* and *conceptions.* They said that these two terms “…refer to differing levels of conceptualisation” (p. 212) but when the model as revised a decade later, Strike and Posner (1992) explained their differences, “We used the word conception to mark the plurality and internal complexity of these objects of change, and to distinguish it from the term concept as used in normal discourse.”(p. 148)

Indeed, different definitions have been assigned to what is called a concept. From the philosophical perspective, Thagard (1992b) proposed a taxonomy of the nature concepts based on philosophers’ theoretical views—*entities* (nonnatural, mental, linguistic or abstracted) and *non-entities* (fictions or emergent states). He also enumerated 10 possible functions of a concept: *categorisation, learning, memory, deductive inference, explanation, problem solving, generalisation, analogical inference, language comprehension* and *language production* (p. 22).

White (1994), defined a concept simply by two meanings: one concerns classification of objects with names and one is about “all knowledge that a person has, and associates with, the concept’s name” (p. 118). To Schwedes and Schmidt (1991), “[a] concept is not a single idea but a conglomerate of connected ideas which can explain a certain class of problems or situations” (p.188). Smith (1991) identified the connectedness in Ausubel’s (1968) notion of meaningfulness in a concept that is nonarbitrarily related to other concepts in an individual’s cognitive structure. Novak (1996) defined a concept as “a perceived regularity in events or objects designated by a label (usually a word)” (p. 32) but Novak (1998) later extended this definition to include the notion that concepts can combine to form propositions and are hierarchically structured. Unlike scientists and science educators, sociologists distinguish scientific concepts from everyday concepts and that scientific concepts must be “consensually defined within the communities of scientists” (Denzin, 1989, p. 53). In the same vein, conceptual change researchers Ferrari and Elik (2003) recently added a social dimension to the definition of concepts by defining concepts as “the constituents or the smallest units of thought and that they are shared among people in a society (and sometimes, around the world).” (p. 25)

*Representations* are the ways we communicate ideas or concepts by representing them either *externally*—taking the form of spoken language (verbal) written symbols (textual), pictures, or physical objects or a combination of these forms—or *internally* when we think about these ideas (Hiebert & Carpenter, 1992). Within the field of artificial intelligence, *knowledge representation* is a subfield which is “concerned with techniques in representing information in a computer for intelligent processing” (Thagard, 1992b, p. 5).

*Conceptions* are not easy to define. White (1994) defined conceptions simply as “systems of explanation” (p. 118). Conceptions can be regarded as the learner’s *internal representations* constructed from the external representations of entities constructed by other people, e.g., teachers or software designers, from their own conceptions of these entities (Thorley, 1990). Duit and Glynn (1996) considered conceptions as learners’ *mental models* of an object or an event. According to Vosniadou (1994), mental models are “dynamic and generative representations which can be manipulated mentally to provide causal explanations of physical phenomena and made predictions about the state of affairs in the physical world” (p. 48).

### 2.2.4 Conceptual Change Model

Constructivist approaches appeared to be a common core for conceptual change learning and instruction in science education. The theoretical framework of Posner et al.'s (1982) conceptual change model (CCM) is the leading paradigm that has been guiding research and instructional practices in science education for many years (Vosniadou, 1999).

Posner et al. (1982) traced their development of the model from a number of previous studies on *misconceptions* or *alternative conceptions*[9] in the 1970s and Piaget's (cited in Posner et al., 1982) similar theory that focused more on students' ideas in logical thinking than on the actual content of their ideas. The CCM was largely derived from contemporary philosophy of science, in particular the work of Kuhn (1970), Lakatos (1970), and Toulmin (1972) to address a central question of "how concepts change under the impact of new ideas or new information" (Posner et al., 1982, p. 221). It is intended to illuminate learning and has some pedagogical implications (Hewson, 1981). Its philosophical basis is largely epistemological. Posner et al.'s model uses an analogy between the conceptual change in scientific research and student learning in the classroom. In scientific communities, conceptual change takes place first in Kuhn's "normal science" (p. 212) and then in "scientific revolution" (p. 212) whereas in student classroom learning the two phases are called *assimilation* and *accommodation*. In assimilation, a student uses his or her own existing conceptions to learn new concepts whereas in accommodation, the student must replace or reorganise his or her existing conception with which the new conception is not reconcilable. Hewson (1982) used "conceptual capture" (p. 76) for assimilation and "conceptual exchange" (p. 76) for accommodation.

Posner et al.'s (1982) initial CCM was expanded and improved by Hewson (1981; 1982), Hewson and Thorley (1989) and Thorley (1990) in two major ways: conceptual change that involves metacognitive learning and metaconceptual learning (see section 2.2.6.2). It was revised by Strike and Posner (1992) to include affective and social issues and a developmental and interactionist view of conceptual ecology. Moreover, as will be discussed in the following sections, Pintrich, Marx, and Boyle (1993) challenged Posner et al.'s metaphor of *student as scientist* as having serious

[9] Throughout the thesis, *alternative conceptions* will be used for what is commonly known as *misconcepionts* which is a misnomer (see Wandersee, Mintzes, & Novak, 1994).

limitations if the motivational factors affecting student learning are not considered. More importantly, the traditional CCMs "do not fully account for learner's intention in the change process" (Sinatra & Pintrich, 2003a, p. 6) (see section 2.2.12).

### 2.2.5 Two Research Approaches to Conceptual Change Learning

Posner et al.'s (1982) CCM has since spawned a plethora of conceptual change research theories and practices. Two research approaches based on two relatively independent research traditions have greatly contributed to the understanding of conceptual change: the science education approach and cognitive developmental approach (Vosniadou, 1999).

The first research approach follows the original model which describes learning as a process in which a person changes his or her personal conception of science when the new conception is intelligible to, plausible to and fruitful for the learner or a source of dissatisfaction to the learner. According to Vosnidiou (1999), although most of the researchers (diSessa, 1993; Driver & Easley, 1978; Spada, 1994) had been influenced by Piagetian constructivist epistemology, they tended to focus on the content of science and how to teach science in order to promote conceptual change. The second approach to the conceptual change research is that taken by cognitive developmentalists such as Carey (1985; 1986) and Vosniadou (1994; Vosniadou & Brewer, 1987; Vosniadou, De Corte, Glaser, & Mandl, 1996) whose perspective focuses on knowledge restructuring with development. Accordingly, not only do students learn new knowledge but they also acquire developmental capabilities such as metacognitive awareness that support knowledge restructuring (Sinatra & Pintrich, 2003a).

### 2.2.6 Conceptual Ecology, Status and Thorley's (1990) Categories

According to Posner et al.'s (1982) CCM, the learner's conceptual ecology provides the context in which conceptual change occurs. There are four conditions in the conceptual ecology: *dissatisfaction*, *intelligibility, plausibility*, and *fruitfulness.*

#### *2.2.6.1 Conceptual Ecology and Conditions for Conceptual Change*

The original CCM of Posner et al. (1982) used Toulmin's (1972) metaphor of conceptual ecology that describes students' existing conceptual structure as the components of an iconological system in the environment. This is based on "…the ecological demands of the particular situation and the criteria for judging conceptual novelties…" (Toulmin, 1972, p. 396).

The original model, as discussed in the previous section, also uses the metaphor of the student as scientist in interpreting his or her conceptual learning. The key factor to conceptual change is the status of the student's new conception, which measures whether he or she accepts the new conception or the old according to the four conditions for change (Hewson, 1981, 1982; Hewson & Hennessey, 1992; Posner et al., 1982). First, students must become dissatisfied with their existing conceptions. Second, they must regard their new conception as intelligible. Third, they must find their new conceptions initially plausible. Finally, they must find their new conception fruitful. When there is dissatisfaction with the current conception, the second condition serves as a prerequisite for the third which in turn serves as another for the fourth. As such, the status of a new conception can be—not intelligible, intelligible (I), intelligible-plausible (IP) or intelligible-plausible-fruitful (IPF). Recently, Hewson and Lemberger (2000) clarified that "dissatisfaction is a psychological response to the other, epistemological, conditions"(p. 111). Accordingly, the fall of the status of one's conception—as intelligibility, plausibility and/or fruitfulness respectively decreases within the learner's conceptual ecology—leads to *dissatisfaction* which is "a psychological state, not be confused with status itself" (p. 111).

#### *2.2.6.2 Thorley's (1990) Status Analysis Categories*

Based on Hewson's (1981; 1982) work, Thorley (1990) constructed the *status analysis categories*[10] for interpreting the status of students' conceptions in terms of I, IP or IPF (see Table 2.3) in his classroom study of status-related conceptual learning of science.

[10] Thorley (1990) initially used "discourse analysis categories"(p. 113), referred to later by Hewson and Lemberger (2000) as *status analysis categories,* which I have used throughout the thesis.

Table 2.3

*Categories for Analysing Conceptual Status Adapted from Hewson and Lemberger (2000), and Thorley (1990)*

| Status of Conceptions | Status Elements (in upper case)[a] |
|---|---|
| INTELLIGIBILITY | *Representational modes:* |
| | INTELLIGIBILITY ANALOGY (analogy or metaphor to represent conception) |
| | IMAGE (use of pictures or diagrams to represent conception) |
| | EXEMPLAR (real-world exemplar of conception) |
| | LANGUAGE (linguistic or symbolic representation of conception) |
| PLAUSIBILITY | *Consistency factors:* |
| | OTHER KNOWLEDGE ('reasoned' consistency with other high-status knowledge) |
| | LAB EXPERIENCE (consistency with laboratory data or observations) |
| | PAST EXPERIENCE (particular events consistent with conception) |
| | EPISTEMOLOGY (consistency with epistemological commitments) |
| | METAPHYSICS (refer to ontological status of objects or beliefs) |
| | PLAUSIBILITY ANALOGY or P ANALOGY (another conception is invoked) |
| | *Other factors:* |
| | REAL MECHANISM (causal mechanism invoked) |
| FRUITFULNESS | POWER (conception has wide applicability) |
| | PROMISE (look forward to what new conception might do) |
| | COMPETE (explicitly compare two competing conceptions) |
| | EXTRINSIC (associate new conception with experts) |

[a] The status elements in their upper case will be used in analysing students' conceptual status in Chapter 8.

Using Thorley's status analysis categories, Lemberger (cited in Hewson & Lemberger, 2000) studied conceptual change and problem solving during a senior genetics course. Lemberger's findings highlighted the importance of status that students used in considering the intelligibility in resolving an anomaly while solving problems. Hewson and Lemberger (2000) argued that "status—a construct originating in conceptual change theory—is the hallmark of all forms of conceptual learning." Thorley's (1990) case studies on students' status-related learning in science classrooms further extended the importance of status and proposed another a new construct of *metaconceptual learning* related to metacognition in conceptual learning. In developing the categories for analysing status-related interactions in the classroom discourse, Thorley distinguished the categories which are *metacognitive* and *metaconceptual*. Accordingly, a learner's reflection on or reference to the content of conceptions themselves is categorised as metaconceptual whereas a learner's reflection on or reference to thinking or learning processes related to particular conceptions is metacognitive. Thorley's method will be used in the analysing the students' gene conceptions in the cross-case analyses of students' conception status in Chapter 8.

### 2.2.7 Multidimensional Framework

For more than two decades, researchers have endeavoured to advance Posner et al.'s (1982) CCM beyond the original epistemological perspective. Tyson et al.'s, (1997) multidimensional CCM has proved to be a robust framework for interpreting classroom conceptual learning of science in a number of recent case studies (Harrison & Treagust, 2001; Venville & Treagust, 1998).

As reviewed by Harrison and Treagust (2001), there are at least five perspectives from which to look at the multidimensional model: epistemological (Posner et al., 1982), developmental (Carey, 1985), ontological (Chi, Slotta, & de Leeuw, 1994), explanatory coherence (Thagard, 1992a), and motivational (Pintrich et al., 1993). I have already reviewed the original model which is largely epistemological and the contributions of Hewson and his co-authors (Hewson & Lemberger, 2000; Hewson & Hewson, 1992; Hewson & Thorley, 1989) to the status of conceptions. In Chapter 8, I will revisit the literature when I report on the cross-case analyses of selected students' conceptual learning. In the next sections, I will review the literature on the motivational and ontological perspectives, and then briefly on the notion of *explanatory coherence*.

### 2.2.8 Conceptual Learning: The Social/Affective Dimension

Pintrich et al. (1993), on highlighting "the theoretical difficulties of a cold, or overly rational, model of conceptual change" (p. 167), suggested applying research on student motivation to the process of conceptual change. They discussed four motivational constructs—*goals, values, self-efficacy,* and *control beliefs*—as potential mediators of conceptual change. As will be discussed later in this chapter, a decade on since their provocative paper, Pintrich et al.'s motivational perspective has now developed into a new direction—*intentional conceptual change* (see section 2.2.12).

#### *2.2.8.1 Examples of Affective Learning Outcomes using Analogies*

Pintrich et al.'s (1993) motivational perspective is the basis of the social/affective dimension in Tyson et al.'s (1997) multidimensional conceptual change framework. Previous research has provided a number of examples of affective learning outcomes when teachers used analogies (Treagust, 2001).

As will be reviewed in detail (see section 2.3.1.1), the use of analogies as instructional strategies for conceptual understanding is still a controversial issue. Although the use of analogies in teaching can facilitate comprehension and problem solving, their use may lead to misunderstanding and thus alternative conceptions (Friedel, Gabel, & Samuel, 1990; Glynn, 1991; Venville & Treagust, 1997). Nevertheless, research studies indicated that analogies used by science teachers do help create interest and motivation besides facilitating conceptual understanding (Treagust, 2001).

To illustrate how analogies can be motivational in facilitating conceptual change, I will briefly describe three Australian examples here. First, in a study to examine how Australian science teachers used analogies during their regular teaching, Treagust, Duit, Joslin, and Lindauer (1992) found that teachers recognised that analogies can help students relate abstract concepts to the real world by promoting visualisation of some invisible abstract phenomena. As will be discussed in Section 2.3.3.3, visualisation is intrinsically motivating and can facilitate conceptual understanding through making connections between concepts. The second example is about the use of an analogy in teaching Year 10 physics. The analogy used by an experienced teacher in explaining light refraction appeared to provide useful avenues for engendering students' interest as well as conceptual change (Harrison & Treagust, 1993). In the third example, Venville and Treagust (1996) show that the bucket-and-pump analogy for the heart contributed to conceptual change by motivating the low-achieving students in a Year 10 biology class. Venville and Treagust concluded that the simplified analogy of the heart made the content easier to learn and motivated students' learning by raising their self-efficacy. Self-efficacy is one of the four motivational constructs highlighted in the Pintrich et al.'s (1993) seminal paper.

#### *2.2.8.2 Interest, Learning and Conceptual Change*

As this research is about the use of computer-based multiple representations, the social/affective dimension is to consider the role of interest and motivation in conceptual learning of genetics when the teachers used the computer program *BioLogica* in their teaching.

The assumption about the role of *interest* and its implications for meaningful learning can be traced to Herbert (1806-1865) of the 19th Century who developed a theory of interest based on philosophical and psychological considerations. The relation between interest and learning continued to be further developed by many thinkers in the 20th century (Krapp, Hidi, & Renninger, 1992). Thereafter, the concept of interest has been reconceptualized in various discrete research approaches or different aspects of interest such as *attention*, *curiosity*, *emotion*, *attitude* and *motivation*. Within the motivation theory, *achievement motivation* (Atkinson & Raynor, 1974), *intrinsic motivation* (Malone & Lepper, 1987) and *flow* (Csikszentmihalyi, 1975, 1992) are interest-related constructs. Recently, there has been renewed attention in research on the construct of *interest* (Krapp et al., 1992).

As Krapp et al. (1992) put it, interest being a psychological state is affected by situation-specific factors that bring about interest. As such, there are basically two types of interest: *individual interest* and *situational interest*. Individual or personal interest represents personality-specific orientations, reference valuations, or awareness of possibilities for actions (Krapp et al., 1992). In school learning, personal interest refers to the student's preexisting degree of interest in a given subject matter conceptualised as "a relatively stable, enduring disposition of the individual" (Pintrich & Schunk cited in Andre & Windschitl, 2003, p. 183). Unlike personal interest, situational interest refers to the interest that is "generated primarily by certain conditions and/or concrete objects (e.g., texts, film) in the environment." (Krapp et al., 1992, p. 8). In this context, the salient features such as visualisation in computer-based multiple representations provide situational interests to motivate student learning. From a new perspective of intentional conceptual change (see section 2.2.11), Andre and Windschitl (2003) proposed a model that "interest influences intention to engage in the cognitive processing necessary for conceptual change" (p. 182-183). This will be further discussed later in this chapter.

#### *2.2.8.3 Motivation, Learning and Conceptual Change*

School learning need not be boring, frustrating and unpleasant as the instructional environment can be designed to motivate students to learn in the absence of obvious external rewards or punishment (Malone & Lepper, 1987).

Motivation can be either extrinsic (e.g., reward for an activity) or intrinsic (e.g., interest in an activity). Malone and Lepper (1987) developed a taxonomy of personal intrinsic motivations: *curiosity*, *control*, *challenge*, and *fantasy*, and interpersonal intrinsic motivations: *cooperation*, *competition*, and *recognition*, which they identified in children playing with computer games. Accordingly, an activity is intrinsically motivating if people engage in it for its own sake but not because of some external reward or punishment. This taxonomy has provided some useful categories in this research for interpreting the students' fun and enjoyment in learning with *BioLogica* (see Chapter 4). The visualisation effects in the interactive computer multimedia appear to make the instructional program motivating and engender student understanding (Kozma, 1997; Wu, Krajcik, & Soloway, 2001).

Recently, there has been a shift in focus from a personal motivation perspective to one that takes into account classroom contextual factors (see for example, Hickey, 1997). Such a shift is in keeping with the social constructivist approaches, particularly Vygotsky's (1978) notion of the zone of proximal development (see for example, Carter, Westbrook, & Thompkins, 1999; Howe, 1996) and social/affective dimension of conceptual learning research (Tyson et al., 1997). As Carter et al. argued, if the use of tools (e.g., those in *BioLogica*) in learning a concept is outside the students' zone of proximal development, the students could not use these tools to develop their understanding of that concept. The teacher's role appears important in this regard. Another aspect of the social/affective dimension of conceptual learning—related to the interpretation of student interaction with *BioLogica* in the first case study—is about *mindfulness* in learning (Jonassen, 2000; Salomon & Globerson, 1987). This construct will be reviewed in the third part of this chapter together with the multiple representations (see section 2.3.6.3).

### 2.2.9 Conceptual Change as Ontological Change

According to Monk (1995), knowledge must have an ontological status and an epistemological justification. Monk defines ontology simply as something "about the nature, of things in the world: the what" whereas epistemology is "about how you know what you know" (p. 129). Based on epistemological presuppositions, Chi (1992) proposed three basic ontologically distinct categories to which physical entities of the world can belong. The three ontological categories, updated by Chi, Slotta, and de Leeuw (1994), are *matter, processes* and *mental states* (see Figure 2.8). They are ontologically distinct categories because no one category is a superordinate of another. On this premise, Chi (1992) distinguished two kinds of conceptual change: a change within an ontological category or a change across ontological categories.

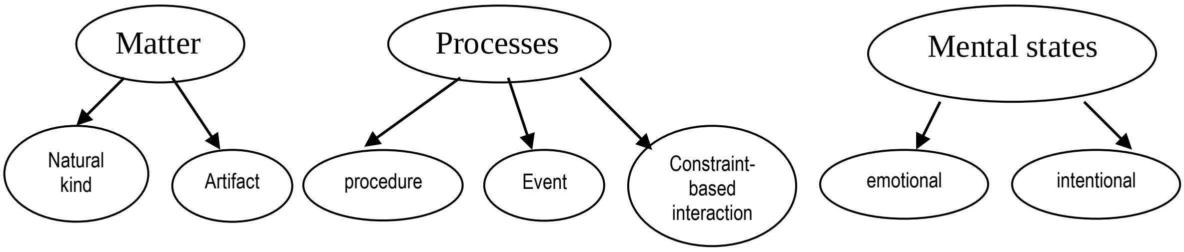



*Figure 2.8* Ontological trees showing three ontologically distinct entities (matter, processes and mental states) in the world (adapted from Chi et al., 1994, p. 29).

#### *2.2.9.1 Conceptual Change Within and Across Ontological Categories*

Chi (1992) asserted that conceptual change within an ontological category, i.e., within the tree, involves gradual change whereas conceptual change across ontological categories, i.e., between the trees, is more difficult for learners to achieve and is called radical conceptual change.

Chi et al. (1994) developed a theory to explain the severe difficulties which students often show when learning certain scientific concepts involving radical conceptual change that requires the reassignment from one ontological category to another, that is, from matter (things) to processes (Chi et al., 1994). This theory is known as the *incompatibility hypothesis* because the learning difficulty stems from an incompatibility between the categorical representations that students bring to an instructional context. Thus, like the concept of heat, light, forces and electricity

(Reiner, Chi, and Resnick cited in Chi, 1992), the concept of genes are treated as substance-based entities in that students conceptualise genes as particles on a chromosome, that is, they belong to the ontological category of matter but not to that of processes—a gene being a set of productive sequence of instructions for protein synthesis (Venville & Treagust, 1998). Thus, according to Chi et al., the conception of genes, in its sophisticated form, belongs to a subcategory of processes called *constraint-based interactions* (see Figure 2.8). Information in genes functions to produce protein products only as defined by relational constraints among several states of the genes, e.g., dominant or recessive, homozygous or heterozygous, or autosomal or sex-linked, and even by environmental constraints, e.g., a precursor chemical or light necessary for the production of the protein products.

#### *2.2.9.2 Conceptual Change by Enrichment and Revision*

Conceptual change does not occur easily as students often hold preinstructional conceptions which are deeply rooted in everyday experiences and are continuously supported by such experiences (Duit, 1999).

Research studies on children's mental models of physical sciences have revealed that children's interpretation of scientific information is constrained by their deeply entrenched presuppositions (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). For example, studies of children's representation about the earth's shape (Vosniadou & Brewer, 1992) indicated that children had much difficulty in constructing a scientific representation of the earth as being spherical. Using the *framework theory* and *presuppositions view*, Vosniadou (1994) explained that unlike simplest form conceptual change by *enrichment* or addition of new information to an existing theoretical framework through the mechanism of accretion, conceptual change by *revision* is particularly difficult. This is because it requires the revision of fundamental ontological and epistemological presuppositions that form the foundations of our knowledge base. Like Chi's radical conceptual change across ontological categories (see section 2.2.9.1), Vosniadou argued that conceptual change by revision is difficult for students because revision of the entrenched presuppositions is "likely to have serious implications for all the subsequent knowledge structures which have been constructed on them." (p. 49). As Duit (1999) pointed out, students may not have dissatisfaction with their preconceptions because the deep-rooted preconceptions are well defined and consistent. Even if they do become dissatisfied with the old conception and the new appears to be intelligible, they do not have conceptual change because they do not believe in the new conception.

As discussed in part one (section 2.1) of this chapter, when confronted by anomalies, the early geneticists adopted a number of reasoning strategies to resolve the anomalies during the theory change of the gene (Darden, 1992). Like scientists, when confronted with anomalies in their learning, students adopt some strategies to resolve the anomalies before they can undergo conceptual change (Chinn & Brewer, 1993). Chinn and Brewer considered the role of deeply entrenched beliefs as impediments to conceptual change:

> Confronted with a piece of anomalous data, "the individual who holds a deeply entrenched [prior] theory will seek to ignore it, reject it, exclude it, holds it in abeyance or reinterprets it. If hard pressed by anomalous data, the individual may make peripheral changes to the theory. Only if confronted with very convincing anomalous data will the individual abandon an entrenched belief. (p. 15)

This is again conceptual change by revision of specific theory or difficult revision of framework theory according to Vosniadou (1994).

#### *2.2.9.3 Co-existence of Naïve and Scientific Conceptions*

Chi (1992) asserted that "a concept may continue to remain on the original tree, even though its corresponding counterpart has developed on the new tree" (p. 135). This concurs with Driver et al.'s (1994) ideas of the ontological perspective of looking at the co-existence of students' informal and formal conceptions of learning science in the classroom. According to Driver et al., students' informal naïve conceptions that they bring to the classroom can co-exist with the formal scientific conceptions they learn in the classroom.

Thagard (1992b) similarly proposed that children's conceptual change may entail a set of new beliefs with more explanatory coherence but still keep their previous beliefs, which can be used in non-academic contexts. I will revisit this aspect again in Chapter 8 as both genes as matter and genes as processes/constraint-based interactions have their value in understanding mechanisms in genetics.

### 2.2.10 Explanatory Coherence

From a cognitive/computational perspective, Thagard (1992b) considered the theory of explanatory coherence as central to the general theory of change in science based on his analysis of the contributions of explanatory coherence to seven scientific revolutions—Copernicus' sun-centred system of planets, Newtonian mechanics, Lavoisier's theory of oxygen, Darwin's theory of evolution, Einstein's relativity theory, quantum theory and the geological theory of plate tectonics.

Thagard (1992b) argued for the advantage of a cognitive/computational approach to understanding of science over traditional philosophical or sociological approaches in that it can specify in detail the psychological mechanisms that lead to scientific discoveries. He also argued that " [t]he transition to new conceptual and propositional systems occurs because of the greater explanatory coherence of the new propositions that use the new concepts" (p. 9). Accordingly, explanatory coherence best accounts for the theoretical choices made by scientists in the growth of scientific knowledge. In reviewing the work of developmental psychologists about children learning like scientists—including Piaget, Carey (1985), Keil (1989), Vosniadou and Brewer (1987), and Chi (1992)—Thagard asserted that children may use explanatory coherence in revising and rejecting old conceptual systems although there has not been enough empirical evidence to support this assertion. He therefore suggested that science educators "investigate whether explanatory coherence plays a role in children's belief revision and rejection of old conceptual systems" (p. 261). Similarly, as pointed out by diSessa (1993), students do use explanatory frameworks but they are not well-organised and lack the systematicity and coherence of experts. Thagard further suggested that one agenda of research on conceptual change is to "[d]etermine whether children and students can be taught a greater sensitivity to explanatory coherence issues, and whether this sensitivity can lead them to learn new scientific theories more readily" (p. 261).

Vosniadou et al. (2001) asserted that researchers need to take into consideration that students are often not aware of the presuppositions and beliefs that constrain their learning. As such, they called for fostering students' development of *metaconceptual awareness* and the construction of *explanatory frameworks* with greater systematicity, coherence, and explanatory power.

### 2.2.11 Types of Conceptual Change

Whereas Posner et al.'s (1982) CCM describes learning as a process in which a person changes his or her conceptions by *capture* or *exchange* (Hewson, 1982), various types of conceptual change and the degrees of change have been proposed since the 1970s. The differences in these proposals often lie in the different theoretical perspectives of their proponents (see Table 2.4).

Table 2.4

*Some Major Types of Conceptual Change and the Degrees of Change*

| Theoretical Perspective | Theorist(s) | Forms of Conceptual Change<br>(→ Indicates the change or the transition in a continuum of change) |
|---|---|---|
| Paradigm shift | Kuhn (1970) | Normal science → Scientific revolution |
| Epistemological | Posner et al. (1982); Strike and Posner (1992) | Accretion → Assimilation/Accommodation |
| Epistemological | Hewson (1981; 1982); Hewson and Hewson (1992) | Rote memorisation → conceptual capture / exchange |
| Conceptual revolution | Thagard (1992b) | 1.Add instance …→ 6.Add new concept … → 9.Tree switching<br>(9 degrees through a continuum) |
| Developmental | Carey (1985) | No restructuring → Weak/strong restructuring |
| Epistemological Ontological | Vosdiadou (1994); Vosniadou and Brewer (1987) | Enrichment → Revision of specific theory → Revision of framework theory |
| Ontological | Chi (1992) and Chi et al. (1994) | No ontological change → Within/Across ontological categories (radical conceptual change) |
| Social /affective | Pintrich, Marx & Boyle (1992), Venville and Treagust (1996) Georghiades (2000) | Less self-efficacy → more self-efficacy<br>Less metacognitive control → more metacognitive control<br>Less durable learning/No transfer → More durable learning/transfer |

I consider the types and degrees of change in this section from multiple perspectives. Of these types of conceptual change, the students' status of their conceptions (Hewson & Lemberger, 2000; Hewson & Hewson, 1992; Thorley, 1990) appears to offer the most useful way to consider the process and outcome of conceptual change in classroom learning. According to Harrison (1996) and Venville (1997), these different types of conceptual change can take place at different levels and to different degrees. For example, some authors described the types of change as contrasting forms, such as easy or difficult changes (Carey, 1985; Hewson, 1981, 1982, 1996; Posner et al., 1982), some as being at several levels (Chi et al., 1994; Vosniadou, 1994) and some as a continuum (Thagard, 1992a). Partly based on Harrison's (1996) and Venville's (1997) extensive review and new ideas from Sinatra and Pintrich's (2003a) review, I have summarised in Table 2.4 the major forms of conceptual change relevant to this research.

### 2.2.12 Limitations of Posner et al.'s (1982) Two Metaphors

As mentioned briefly in section 2.2.4, Pintrich et al. (1993) challenged the two metaphors originally used in Posner et al.'s (1982) CCM as having serious limitations if conceptual change is considered as a cold and rational process without looking at the related motivational constructs (goals, values, self-efficacy, and control beliefs).

According to Pintrich et al. (1993), the metaphor of the individual student as scientist is not appropriate for two reasons. Unlike students, scientists make sense of their results of their research with their prior theoretical beliefs and conceptual models. An individual scientist is also part of larger community of their particular area of research with a common goal of understanding which most scientist internalise as their personal goal (see the example of Watson and Crick in section 2.1.8.4). Similarly, the metaphor of the conceptual ecology has its limitations. The metaphor of the ecology for the conceptual change balances the alternative conceptions within the students' conceptual structure as analogous to the operation of an ecosystem. Ecosystems cannot depict learner's ontological change. Nor can they imply that learners are purposeful. Learners' thinking is driven and maintained by intentions, goals, purposes and beliefs. Both critiques point to the need to consider the affective, social and motivational aspects of conceptual learning. The construct *intentional learning* (Bereiter & Scardamalia, 1989) has now developed into *intentional conceptual change* (Sinatra & Pintrich, 2003b), a new line of conceptual change research.

As Sinatra and Pintrich (2003a) explained, the idea of intentional conceptual change came from Bereiter and Scardamalia's (1989) work about the intentional learner and Pintrich et al.'s (1993) perspective that there is more to conceptual change than cold cognition. An *intentional learner* is "one who uses knowledge or beliefs in internally initiated, goal directed action in the service of knowledge and skill acquisition" (Sinatra cited in Vosniadou, 2003, p. 378). Intentional conceptual change is "the goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge" (Sinatra & Pintrich, 2003a, p. 6). Sinatra and Pintrich called for more intentional conceptual change being fostered in school learning as this may result in deeper and longer change of knowledge in students.

To end the second part of this chapter, I quote Duit's (1999) suggestion about the future agenda of conceptual change research: "Further close cooperation of research in science education and cognitive science appears to be most promising to investigate both the fine structure of conceptual change processes and the impact of support conditions of conceptual change" (p. 282).

## 2.3 Learning with Multiple Representations

Many scientific phenomena, such as those from cosmology, geology, chemistry or biology, are beyond the learner's temporal, perceptual and experiential limits (Kozma, 2000). Consequently, our understanding of these phenomena depends on "our ability to access and interact with them indirectly" (p. 12). When television programs and films were the most influential media in the 1970s, Salomon (1979) posed two questions about the interaction of media, cognition and learning. The first question concerned how we can represent knowledge in various symbolic systems. The second one was about how each learner comes to appreciate such presentations of knowledge. These two questions remain pertinent even in the 21st century when the *Zeitgeist* of the learning media is information and communication technologies (ICT).

### 2.3.1 Analogies, Multiple Analogies and MERs

The famous 17th century astronomer Johannes Kepler (cited in Polya, 1954) once wrote: “And I cherish more than anything else the Analogies, my most trustworthy masters. They know all the secrets of Nature, and they ought to be least neglected in Geometry” (p. 12). Given the historical importance of analogical reasoning in scientific discovery, insights and explanations, analogies have been used by textbooks and classroom teachers in explaining science concepts to students.

#### *2.3.1.1 Use of Analogies in Science Education*

Since the time before computers were used in the classroom, science teachers have been using a range of different representational techniques to present information to students: verbal and written language, graphics and pictures, practical demonstrations, abstract mathematical models and semi-abstract simulations (van Someren, Boshuizen, de Jong, & Reimann, 1998).

More specifically, teachers’ use of analogies, in one or several forms of representation, has been an important line of research into teaching and learning of abstract science concepts, reasoning and problem solving, and for conceptual change (Duit & Glynn, 1996). According to Glynn (1991), an analogy is a process for identifying similarities between different concepts. The familiar concept is called the *analog* and the unfamiliar one the *target*. Whereas the terms *analogy* and *metaphor* are often substituted for each other, analogy is used more often in scientific contexts.

Over the past decades, the research on the use of analogies in teaching and learning of science in schools has been active (see for example, Glynn, 1991; Treagust et al., 1992; Treagust, Harrison, Venville, & Dagher, 1996; Treagust, Venville, Harrison, Stocklmayer, & Theile, 1994; Venville & Treagust, 1996). Analogies are related to models and modelling. Duit and Glynn (1996) considered models as representations of an object or of an event, which are formed by the process of modelling in science and science education. Accordingly, learning science is the reconstruction of the products of modelling in science and analogies and their relatives—such as metaphors, similes or allegories—are at the heart of modelling.

Despite the fact that analogies appear to be useful as strategies in teaching and learning of abstract concepts, they are “double-edged swords” (Glynn, 1991, p. 227) which, when not used cautiously, may lead to miscomprehension and misdirection. Similarly, as chemistry educators Friedel and Gabel (1990) pointed out, the effectiveness of using analogies in instruction is questionable because students may not be familiar with the analogs which teachers used in the analogies. In biology, the problems with analogies used in textbooks and classrooms are threefold: (1) analogies are used by teachers as mechanical clichés, i.e., used without thinking about their meanings; (2) students are not familiar with the analog; and (3) inconsistencies between the analog and the target result in students being unable to map the shared attributes and delineate the limitations of analogies (Venville & Treagust, 1997).

#### *2.3.1.2 Multiple Analogies*

In view of the problems in using analogies, Glynn (1991) suggested using several analogies (for a single concept) which can allow students to examine the concept from more than one perspective. Each perspective (analogy) brings particular features of the concept into a clearer focus; thus students will have a more comprehensive understanding of that concept and its relationship to other concepts.

Along this line of thinking, Harrison (1996) conducted a study of the role of multiple analogical models of atoms and molecules on conceptual change of Years 8-10 students. His findings helped to refine Tyson et al.'s (1997) multidimensional CCM. He concluded that the value of teaching with multiple analogies is one of the most promising lines of pedagogical research in science education. As will be discussed in the following sections, the new perspectives on computer-based multiple representations have now provided a more robust framework to interpret analogical models and their relatives such as metaphors, and images, which have been in use for centuries as vehicles for reasoning. They should also illuminate the ways in which classroom teachers use analogical models and other visual-graphical representations in normal classroom teaching.

#### *2.3.1.3 Multiple Representations*

Whereas the term *multiple representations* applies to both the external representations used by machines and humans, *multiple external representations (MERs)* refers to the computer-based multiple representations in this thesis.

From the cognitive/computational perspectives of multiple representations (Ainsworth, 1999), analogies are but representations using one or two formats or modalities (see section 2.3.3) such as verbal and visual-graphical formats. Multiple external representations (MERs), unlike multiple analogies, are often more realistic representations of the target. MERs of abstract scientific phenomena are different conceptualisations in various forms including analogies and simulations. Multiple representations, when used in interactive computer programs, are often dynamically linked, co-deployed and can be manipulated by users to observe the ensuing changes or *constraint-based interactions* (Chi et al., 1994) of the entities in the phenomenon. Users can also construct their personal mental models and make their thinking visible while solving problems in the computer microworld.

Given the previously cited claim that many scientific phenomena are beyond the learner's temporal, perceptual and experiential limit, it is likely that MERs in interactive multimedia can support learning of these scientific phenomena (Kozma, 2000). Recent findings have indicated that learning with MERs do exert learning demands on the learners, who may not necessarily benefit from such interactive multimedia programs in solving mathematical problems (Ainsworth et al., 1997; Chi et al., 1994), in learning chemical equilibrium (Kozma, 2000) and in learning body movements in physics (Yeo, Loss, Zadnik, Harrison, & Treagust, 1998).

.

### 2.3.2 Dimensions of Multiple Representations

Cognitive psychologists and computational scientists have recently described some commonalities in learning with multiple external representations (MERs). For example, according to de Jong et al. (1998), when confronted with different representations of information, learners have to evaluate and select these representations and to integrate them into their personal knowledge construction process. De Jong et al. made a comprehensive review of the five common dimensions of multiple representations: *perspective, precision, modality, specificity* and *complexity*. The definitions of these dimensions are given in Table 2.5.

According to Nowell (cited in de Jong et al., 1998), perspective is clearly linked to the *knowledge level* where descriptions are given in terms of what one knows or believes. At this level, no attempt is made to specify the symbols or data structures for representing knowledge. Modality and complexity are at the *symbolic* *level* where representations of knowledge, i.e., symbolic structures can be manipulated by mental operations. Precision is both at the knowledge level and the symbolic level, as is specificity. Perspective is at the knowledge level and is most closely related to *ontology* (see Table 2.5).

Table 2.5

*Dimensions of Representations (de Jong et al., 1998)*

| Dimension | Definition | Level |
|---|---|---|
| Perspective | The particular theoretical viewpoint taken in presenting material | Knowledge |
| Precision | The level of accuracy in the description (mainly qualitative vs quantitative) | Knowledge and symbolic |
| Modality | The representation format | Symbolic |
| Specificity | The informational economy of a representation | Knowledge and symbolic |
| Complexity | The amount of information present in a representation | Symbolic |

### 2.3.3 Modality: A Taxonomy of Multiple Representations

Modality is the particular form of expression or representation for displaying information (de Jong et al., 1998). In view of the different ways in which representations of genetic phenomena are used—by *BioLogica*, the teachers and the students—an extensive literature review allowed me to develop a comprehensive taxonomy to categorise these external representations.

A taxonomy of multiple representations is summarised in Table 2.6 under four broad categories with respect to the modality (1) *Verbal-textual*, (2) *Logico-mathematical*, (3) *Visual-graphical* and (4) *Actional-operational* (de Jong et al., 1998; Lemke, 1998b; Lohse, Biolsi, Walker, & Rueler, 1994). Verbal representations can also be called textual or sentential representations, which can be presented either auditorily (e.g., when teachers talk about science) or visually (e.g., when teachers write on the board, display text using overhead projection or let students read printed matter such as textbook or worksheet). These also include mathematical expressions or symbols, e.g., algebraic notations, but when only mathematical equations and symbols are used, they are put into a separate category. Based on Lohse et al.'s (1994) work, visual-graphical representations used in classroom teaching of science in general and genetics in particular can be subcategorised into graphs, icons, pictures, process diagrams, structure diagrams, and tables. To this list, gestures and physical models should also be appended. As for actional-operational representations, these are the teacher's demonstration of experiments or use of physical models, some hands-on classroom activities (other than using the computer) and experiments on genetics. The research into practical work and experiments constitutes another very extensive area of research, which is beyond the scope of this study. Given that there are not many feasible and fruitful experiments that secondary school students can do in genetics, teachers seldom use experiments in their teaching but when they do, these representations still contribute in one way or another to the students' learning of genetics, for example, the experiment to extract DNA from onion tissues in School C (see Chapter 6).

Among these four broad types of representation in Table 2.6, verbal-textual and visual-graphical representations are most relevant to this study which focused on genetics reasoning, In the next two sections, I will briefly review the literatures related to these two types of representation to provide a theoretical background for both the methodology chapters and analyses and interpretations in the results chapters.

### 2.3.4 Verbal and Textual Representations

In the first part of this chapter, the geneticists—from the time of the rediscovery of Mendel's paper to 1926 when Morgan (1926) published his theory of the gene—juggled with the language (German or English) to reason and solve problems while seeking to develop the theory components of the gene. A century later, many students in the schools are grappling with the same language while making sense of Mendelian genetics.

Sutton (1992) argued for the persuasive role of words as well as their thought-crystallising and thought-provoking power in the growth of scientific ideas and in a learner's understanding. However, scientists use a highly specialised language of science that incorporates more than words in communications—graphs, charts, diagrams and mathematical symbols and equations (Jones, 2000). In schools, verbal language (verbal-textual representations) used in the teaching of science has created a barrier for student learning in various areas of science (Bahar et al., 1999; Henderson & Wellington, 1998; Pearson & Hughes, 1988a, 1988b). As Henderson and Wellington argued, “the quality of classroom language is bound up with the quality of learning” (p. 36). In section 2.1.9, I have reviewed that the major difficulty of learning genetics is that it requires multilevel thinking because the knowledge occurs at three levels. It follows that the use of verbal-textual representations alone in teaching is not enough for engendering student understanding of genetics.

Table 2.6

*Taxonomy of Multiple Representations for this Study*

| Type | Subtype | Example in this Study |
|---|---|---|
| Verbal-textual | | Writing, reading texts and talking |
| Mathematical | | Genotypes, genotypic/ phenotypic ratios, probability expression/equations |
| Visual-graphical | Graphs | Line and charts |
| | Icons | Pedigree and symbols |
| | Pictures | Photographs |
| | Process diagrams | Flow charts with arrows |
| | Structure diagrams | Diagram/drawing of DNA/chromosomes/cell |
| | Tables | Tables for recording data, Punnett square algorithm |
| | Gestures | Body movements/facial expressions |
| Actional-operational | Physical models | DNA model, beads-on-a-string model, model of cell divisions |
| | Demonstrations | Experimental results, specimens, human traits |
| | Hands-on activities | Games or any other hands-on activities except computer activities |
| | Experiments | Experiment to extract DNA |

In part two of this chapter (section 2.2), we have seen that concepts can be simply considered as being the classification of objects with names (White, 1994). Terminology, in science in general and genetics in particular, has created a linguistic barrier in school learning (Bahar et al., 1999; Horwitz & Christie, 2000; Johnstone, 1991; Johnstone & Mahmoud, 1980). In exploring the problems of terminology in genetics education, Pearson and Hughes (1988a; 1988b) reviewed the literature, analysed the biology textbooks in the UK and identified three areas that make terminology of genetics confusing and difficult for students as well as teachers—a large number of true synonyms, the misuse of some synonyms and the use of obsolete and redundant terms. They suggested reducing the number of synonyms; clarifying the meanings and use of misused synonyms; and identifying, listing and eliminating the obsolete and redundant ones from the terminology used in schools. The history of genetics in the first part of this chapter has shown that many terms of genetics were used and then subsequently replaced by better ones to reflect clearer understandings of genetics (see section 2.1.4). Besides using the terms, language can be very powerful in teaching and learning of science and mathematics when it is used as analogy, metaphor, metonymy, or simile in explanations (see for example, English, 1997; Martins & Ogborn, 1997; Thagard, 1992a; Venville & Treagust, 1996). Such nonliteral or figurative use of the language can invoke mental models or internal representations in the learner even without real images and graphics. For example, Gentner and Gentner (1983) explored the conceptual effect of people's analogical language. When people discussed about a complex scientific phenomenon such as electricity in analogical terms, they were thinking in terms of analogies or borrowing language from one familiar domain such as flowing fluids to talk about electricity.

In order to contribute to students' ability to make sense of the world, description of things and explanation of these things are critically important activities in classroom teaching (Horwood, 1988). Accordingly, description is to provide pieces of information, not necessarily related, but explanation is to connect between and among pieces of information. As reviewed in the second part, plausibility in conceptual change learning is mainly about how well a learner can explain what he or she understands about the concept. Treagust and Harrison (1999) highlighted the importance of teachers' effective explanation in the classroom and how the expert teachers "draw creative word pictures that both appeal to and inform a diverse group like a class of students" (p. 28). As such, how to verbally explain genetics to students and teach them how to verbalise their understanding is important. As Johnson-Laird (1983) put it, "if you do not understand something, you cannot explain it" (p. 2). Genetics reasoning (Hickey & Kindfield, 1999), the focus of this research, is related to explanation.

In analysing communication using language in the science classroom, Lemke's (1990) study of classroom talk and Ogborn, Kress, Martin, and McGillicuddy's

(1996) study of explanations of science in the classroom are both relevant to this study. Both studies were based on Sinclair and Coultard's (1975) pioneer work on discourse analysis of classroom talk but other perspectives from the areas of science education, and social semiotics[11] were also used. Only a very brief review of Lemke's and Ogborn et al.'s studies is given here but references will be made to these two studies again in the results chapters alongside the analyses and interpretations of classroom interactions.

First, during a science lesson—whole class or group discussions—students and the teacher often verbally interact with one another in a series of *exchanges* in the classroom discourse (Sinclair & Coulthard, 1975). In analysing such discourse, Lemke's (1990) common dialogue patterns are relevant to this study. These dialogue patterns include: (1) *Triadic Dialogue*—the most common pattern in which the teacher asks question, call on students to answer them and then evaluate their answers; (2) *Student-Questioning Dialogue*—a pattern in which students initiate questions on the content of the lesson and the teacher answers them; (3) *Teacher-Student Duolog*—a prolonged series of exchanges between the teacher and one student in Triadic Dialogue or *Student-Question Dialogue*; (4) *Teacher-Student Debate*—a prolonged series of exchanges in which students challenge or disagree with the teacher on the content of the lesson; (5) *True Dialogue*—a pattern in which the teacher and the student(s) ask and answer one another's questions and respond to one another's amendments as in normal conversation; and (6) *Cross-Discussion*—a pattern in which students speak directly to one another about the subject-matter, and the teacher acts as a moderator or an equal participant without special speaking rights. Some of these dialogue patterns were identified in this study and interpreted using the above framework (see the results Chapters 4 to 7).

Second, Ogborn et al. (1996) considered scientific explanations as analogous to stories and summarised four roles of language in meaning-making while explaining science in the classroom : (1) *creating differences*—the teacher explains science by making use of the differences between themselves and their students (e.g., knowledge, interest, power, familiarity of the content etc.); (2) *constructing*

[11] Semiotics is the study of all systems of signs and symbols and how we use them to communicate meanings; social semiotics is a synthesis of several modern approaches to the study of social meaning and social action including semiotics (Lemke, 1990).

*entities*—the teacher explains using some created entities or “new chunks of meanings” (e.g., energy, heat or gene) (p. 14) about which students are to think when the teacher “talked into existence” (p. 14); (3) *transforming knowledge*—the teacher explains the constructed entities using narratives, particularly analogies and metaphors (e.g., an eye as a camera or pituitary gland as the conductor of hormonal system) (see Sutton, 1992); and (4) *putting meaning into matter*—the teacher explains by demonstration and persuades students that things are as they are shown or by imposing meaning into the things (e.g. tissue is to be seen as cells). We shall see in the results chapters that some of the claims for these roles are corroborated by what the five teachers and the students talked about in the classroom where the iconic computer Dragons were new entities in their genetics course.

### 2.3.5 Visual-graphical Representations and Visualisation

Visual-graphical representations constitute an important modality of MERs featured in multimedia. According to Thomas, Johnson, and Stevenson (1996), human vision system simultaneously performs the functions of perceiving and recognising form, colour, texture, motion, and spatial relationships. Computer graphics technology has extended human visual systems to contexts and problem-solving situations beyond our normal vision and thus provides a powerful representation for communicating complex scientific ideas and processes.

Pedagogical use of computer-generated visual representations has been well documented in the literature for facilitating the visual learning process or visualisation in science, particularly in conceptually difficult areas of science and mathematics. It was found that interactive simulation promotes conceptual change in students who are learning Newtonian mechanics by enabling them to explore and visualise the consequences of their reasoning (Hennessy et al., 1995). In a study about learning mathematics using the computer algebra system (CAS), Smith (1997) showed that computer-generated visualisation of three different representations—algebraic, numeric, and graphical forms—helped students to think more critically, to foster new perspectives, to feel more confident in their results, and to understand the relations between different representations. In another study on learning physics, Dixon (1997) found that those who learnt with computer-generated visualisation outperformed the control group in their construction of the concepts of reflection and rotation. In learning conceptually difficult areas of physics such as relative motion, visualisation helped problem solving. For example, Monaghan and Clement (2000) investigated students who interacted with collaborative predict-observe-explain activities with relative motion computer simulations. Students who received animated feedback used mental imagery to solve problems whereas those who received numeric feedback used a faulty mechanical algorithm. In chemistry, Wu et al. (2001) showed that visualising tools can help students make connections between visual and conceptual aspects of representations and thus "serve as a vehicle for students to generate mental images" (p. 821). In learning genetics, visualisation can help students to "make meaningful connection between processes and their observable manifestations (e.g., the connection between meiosis/fertilisation and Mendelian genetics)" (Kindfield, 1992, p. 39).

### 2.3.6 Why Use More Than One Representation?

According to de Jong et al. (1998), there are three reasons for using more than one representation in computer-based learning environments.

First, specific information can best be conveyed in a specific representation. A combination of several representations is likely to display learning material that contains a variety of information. As we have seen in the first part of this chapter, geneticists used graphics and images besides using textual representations in developing their reasoning. Second, problem solving depends very much on having a large repertoire of representations or mental models, switching between them and selecting the appropriate ones. The most important theoretical justification for this reason can be found in *cognitive flexibility theory* (Spiro & Jehng, 1990) which is—as de Jong et al. put it—"the ability to creatively restructure one's knowledge in response to a new problem situation" (p. 32). Third, a specified sequence of learning material is beneficial for the learning process.

### 2.3.7 Benefits of Learning with Multiple Representations

Interactive multimedia computer programs that feature MERs appear to be useful in enhancing students' understanding of science and mathematics but research has shown that there are costs and new challenges (Ainsworth, Bibby, & Wood, 1998; Ainsworth et al., 1997).

According to Ainsworth's (1999) conceptual analysis of existing computer-based multi-representational learning environments (Ainsworth et al., 1997; Dienes, 1973; Hennessy et al., 1995; Resnick & Omanson, 1987), there are three major functions that MERs serve in learning situations—*to complement*, *to constrain* and *to construct*. A functional taxonomy of MERs is shown in Figure 2.9. The following three sections briefly review the functions.

#### *2.3.7.1 Using MERs in Complementary Roles*

The first function of MERs in Ainsworth's (1999) functional taxonomy is to use representations that provide complementary information or support complementary cognitive processes so that learners can reap the benefits of the combined advantages such as using both diagrams and verbal-textual representations.

MERs support learning by providing complementary information. First, the multi-representational environments exploit the differences in the information that is expressed by each representation to allow learners to concentrate on different aspects of a task so that they can likely achieve their goals in the task (Oliver & O'Shea cited in Ainsworth, 1999). Second, MERs can support new inferences by providing partially redundant representations such as a functional diagram of a heating system and a physical map to show the positions of its components (Ainsworth, 1999).

MERs also provide complementary cognitive processes. According to Ainsworth (1999), research has shown that different representations containing equivalent information can still support different inferences. For example, diagrams exploit perceptual processes by grouping the relevant information and then make processes such as search and recognition easier (Larkin & Simon, 1987). Tables support quicker and more accurate reading of data as well as highlighting patterns and regularities whereas equations compactly express quantitative relationships (Cox & Brna, 1995). Second, the multi-representational learning environments present a choice of different representations to cater for the varying degree of experience and expertise of students who have different *representational preferences* (to be discussed in section 2.3.9.3). Third, when learners employed more than one representation as strategies in problem solving, their performance was found to be significantly more effective than that of other problem solvers who used only one representation (Cox & Brna, 1995).

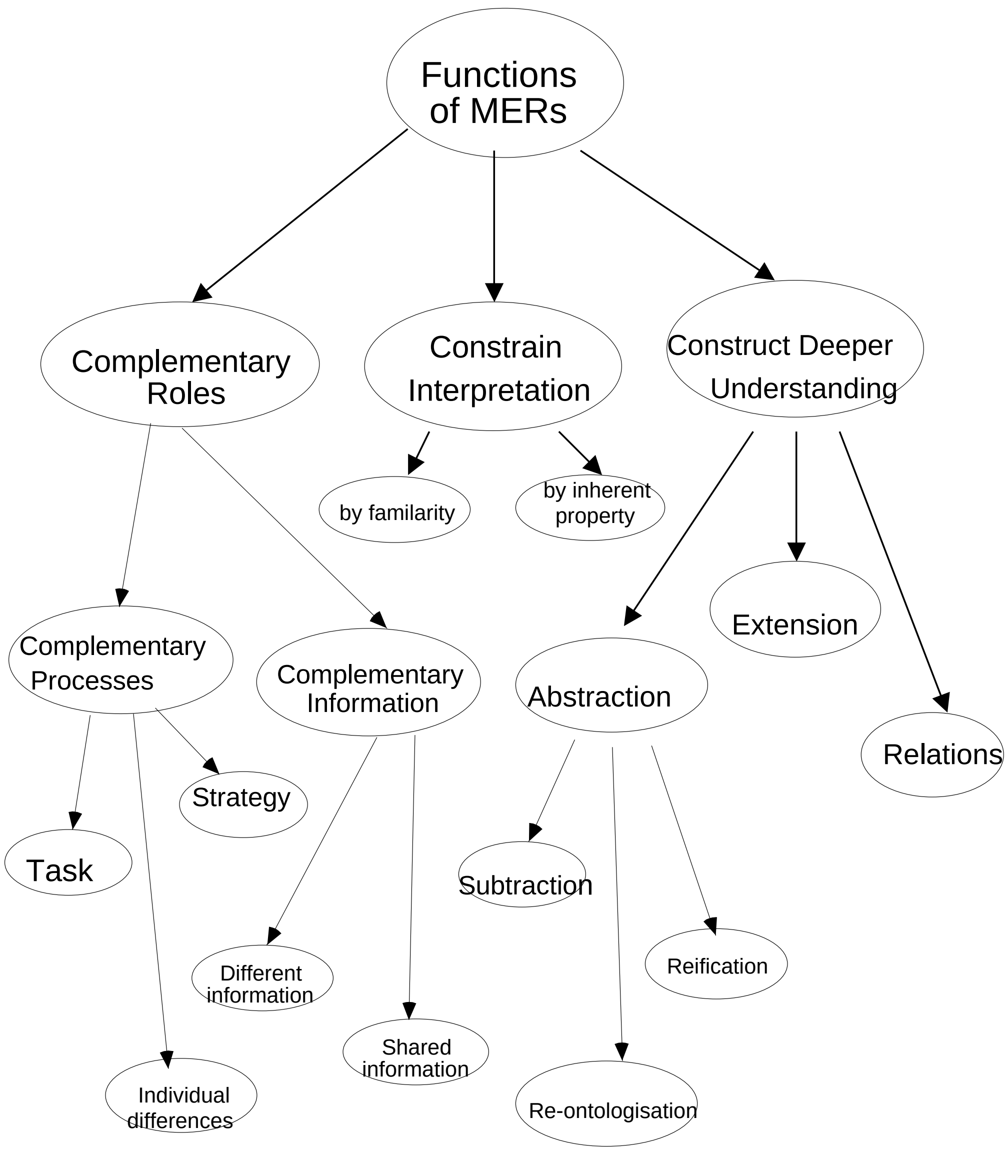



*Figure 2.9* Functional taxonomy of multiple representations (MERs) (Adapted from Ainsworth, 1999, p. 134).

### *2.3.7.2 Using MERs to Constrain Interpretation*

The second function of MERs in Ainsworth's (1999) functional taxonomy is to use a familiar representation to constrain the interpretation (or misinterpretation) of a less familiar representation so as to help learners develop a better understanding of the domain.

There are two ways to achieve this function. First, the computer program can employ a familiar representation to support the interpretation of a less familiar one. Many computer microworlds used MERs for this function. Second, the computer program may exploit inherent properties of one presentation to constrain interpretation of a second. For example, the computer program *Coppers* teaches children about multiple solutions to coin problems. Two representations are provided to show each of the children's solution: one place value representation explicitly shows the arithmetic operations they have performed and one tabular representation expresses the equivalent information (per single row) (see Figure 2.10). The intention is to constrain children's interpretation of equivalence of different sets of coins with the same total value in order to develop the mathematical conception of commutativity in addition.

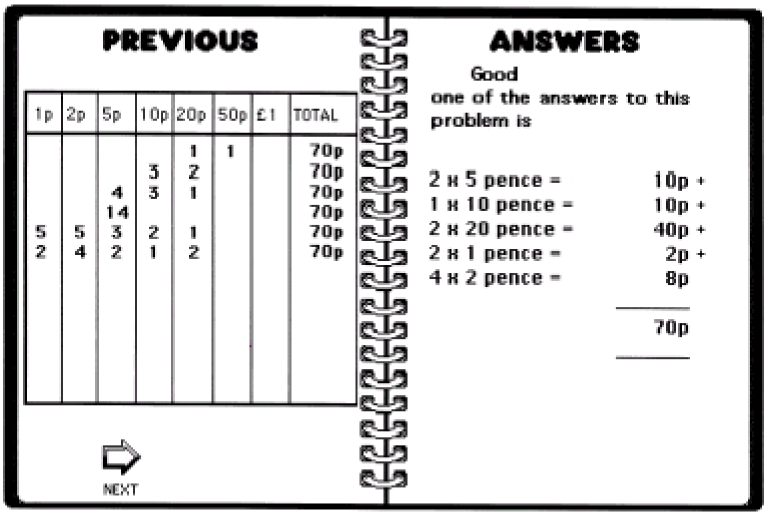



*Figure 2.10* Snapshot of *Coppers*—place value feedback and the summary table (Ainsworth, 1999, p. 140).

### *2.3.7.3 Using MERs to Construct Deeper Understanding*

The third function of MERs is to encourage learners to construct deeper understanding of a phenomenon through *abstraction* of, *extension* from and *relations* between the representations (see Figure 2.9).

Abstraction can be equivalent to *substraction*—to detect and extract only a subset of features from an initial representation or to throw away the details (Giunchiglia & Walsh, 1992). Abstraction can also be conceptualised as *re-ontologisation*. Schoenfeld (cited in Ainsworth, 1999) showed that children developed abstracted sense of number and base ten when they learnt addition and subtraction with two representations. This meaning is comparable to the ontological conceptual change (Chi et al., 1994) (see section 2.2.9.1). The third meaning of abstraction is *reification* in which reified understanding of a process at one level such as an algebraic expression $3(x+5) + 1$ is later understood at a higher level as a mathematical function $f(x) = 3(x+5) + 1$—an abstracted object through deeper understanding (Sfard, 1991).

*Extension* or generalisation is a way of extending knowledge to new situations without fundamentally changing the nature of that knowledge or reorganisation at a higher level (Ainsworth, 1999). Accordingly, within the same domain, the extension involves a learner exploiting an understanding of one representation in order to understanding of a second representation for the same knowledge. In genetics, I can think of the situation when a student who has understood autosomal recessive inheritance pattern is able to understand sex-linked recessive inheritance pattern by extension. In my opinion, this is related to *transfer* in conceptual learning (Georghiades, 2000).

One of pedagogical goals of MERs is to explicitly teach learners how to translate between representations when the representations are co-deployed as exemplified by the *SkaterWorld* environment for learning Newtonian mechanics (Pheasey, O'Malley & Ding cited in Ainsworth, 1999). Ainsworth argued that teaching the *relations* between the representations might encourage abstraction.

## 2.3.8 Costs of Learning with MERs

Some research has indicated that students may not necessarily benefit using MERs. Alongside the benefits, there are the costs of using MERs in learning. For the students to benefit from the learning environments using MERs, learners are faced with three tasks: (1) they must learn the format (i.e., modality) and operators (i.e., complexity) of each representation; (2) they must come to understand the relation (i.e., perspective and precision) between the representation and the domain it represents; and (3) they must come to understand how each representation relates to each other. The benefits and costs of using MERs have implications for designers of multi-representational learning environments (Ainsworth et al., 1998).

Ainsworth (1999) discussed how *translation* across representations should be supported by the software to maximise learning outcomes and suggested further research related to the following principles considered to be speculative: (1) If MERs are designed to support different information and processes, then translation should be *discouraged*. (2) If MERs are used to constrain interpretation, then translation should be *automated*; and (3) If MERs are used to develop deeper understanding, then translation should be *scaffolded*. These should be useful guidelines for designers and users of interactive multimedia featuring MERs. Software developers and teachers are faced with a further important issue—how they can tell when a multi-representational learning environment is successful. Different assessments will be needed for MERs being used for different purposes. Understanding not only each representation in isolation but the relationship between the representations seems to be one criterion for successful learning but assessment should focus on the varying roles of translation (Ainsworth, 1999).

### 2.3.9 Learning with Multiple Representations: Some Theories

New computational perspectives hold that learning difficulties in science and mathematics are of two major types: (1) ontological difficulties at the knowledge level, i.e., how and what to see in the world; and (2) cognitive-computational difficulties at the symbolic level, i.e., how a specific representation format influences a learner to make inferences and come to specific conclusions (Rohr & Reimann, 1998).

It is useful here to briefly review several current learning theories about how students learn with computer-based multimedia that feature MERs. Such review is intended to inform the analyses and interpretations of student learning in the results chapters.

#### *2.3.9.1 A Cognitive Theory of Multimedia Learning*

Of particular relevance to interpreting student learning from *BioLogica* in this study is Mayer and Moreno's (2002) *cognitive theory of multimedia learning* which focuses on multimedia explanations in a computer-based learning environment in which a learner sits in front of a computer monitor.

Built upon a number of studies, Mayer and Moreno's (2002) cognitive theory of multimedia learning encapsulates three theories: (1) *dual coding theory* (Paivio, 1986) that asserts visual and verbal material are processed in different systems; (2) *cognitive load theory* (Chandler & Sweller, 1991) that describes the limited processing capacities of the visual and verbal working memories; and (3) *constructivist learning theory* (Mayer & Wittrock cited in Mayer & Moreno, 2002) that highlights meaningful learning in learners who actively select relevant information, actively organise it into coherent representations, and integrate it with other knowledge. The cognitive theory largely concurs with the new perspectives from the computational sciences in the extensive reviews of recent studies by van Someren, Boshuizen, de Jong, and Reimann (1998) and constructivist ideas although it does not take into consideration the sociocultural and situated cognitive perspectives which appear to be crucial to learning with interactive multimedia (Kozma, 2000).

Three major ideas of the cognitive theory are relevant to this study. First, according to the theory, it is better to present an explanation in words (verbal-textual modality) and pictures (visual-graphical modality) than solely in words. Second, further to using more than one representation, it is better to present corresponding words and pictures simultaneously rather than separately or successively when giving a multimedia explanation. These ideas concur with Ainsworth's (1999) benefits of co-deploying MERs to support learning. Third, a learner's prior knowledge integrates the visual and verbal mental models in constructing deeper understanding of the domain.

To summarise, the cognitive theory of multimedia theory proposes to explain how a cognitively active learner perceives the words and pictures and hold them in the verbal and visual working memories before the learner mentally builds connections between the two. Finally, the learner iteratively builds referential connections between the visual and verbal mental models with prior knowledge (see Figure 2.11).

Interestingly, recent research in neurobiology supports the cognitive theory of multimedia. As reported by Crick and Koch (2002), visual theorists recently agree that the main function of the visual system is to perceive objects and events in the world around us; the information perceived is not sufficient by itself to provide the brain with is unique interpretation of the visual world. It is the past experience or prior knowledge that helps interpretation of what is coming into our eyes.

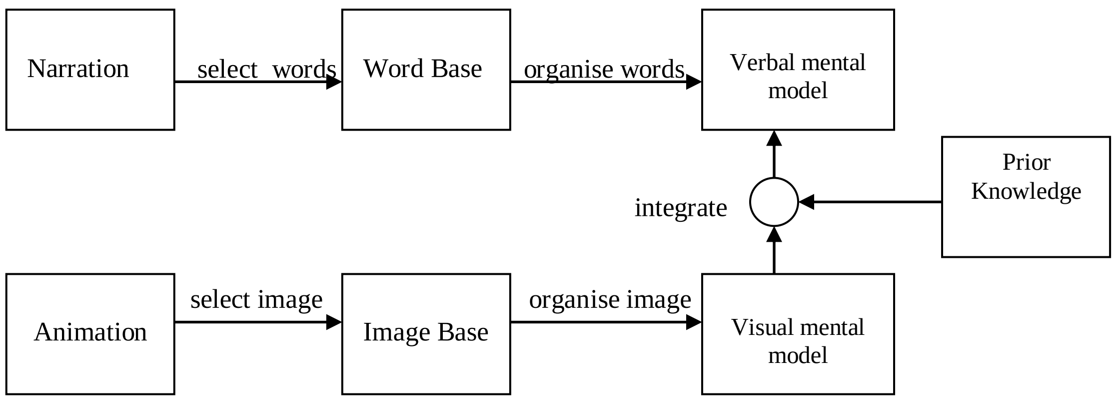



*Figure 2.11* Cognitive theory of multimedia learning (Adapted from Mayer & Moreno, 2002, p. 4).

### *2.3.9.2 Sociocultural Perspectives of Interactions with MERs*

When Kozma (2000) concluded about one of his studies involving MERs, he said, "these new symbols and their symbolic expressions may best be used within rich social contexts that prompt students to interact with each other and with multiple symbol systems to create meaning for scientific phenomena." (p. 45). This is in keeping with Vygotsky's (1978) notion of cultural tools, language (or MERs), which shape students' construction of mental models first between people or as Wertsch (1991) put it, "intermental" (p. 26) and then within the students' minds or "intramental" (p. 26).

Research in learning science and learning science with technology has moved from a largely cognitive approach to one incorporating constructivist, social constructivist, and sociocultural perspectives (e.g. Glaser, Ferguson, & Vosniadou, 1996; Kozma, 2000; Ridgway, 1996). Recent studies have also indicated that the teacher continues to play an important role in effective classroom use of ICT in general (e.g. Lankshear, Snyder, & Green, 2000; Leask & Pachler, 1999) and in using multiple representations in particular (e.g. Kozma, 2000).

#### *2.3.9.3 Representational Preferences*

Mayer and Moreno's (2002) cognitive theory of multimedia learning was developed from the software designer's perspective on how to make instructional design of multimedia more useful in fostering learning. For classroom practitioners, Dekeyer's (2001) notion of individual *representational preferences*—one of a learner's characteristics—appears to be crucial to multimedia learning. This notion is supported by Paivio's (1971; 1986) theory that the modality of input (verbal or visual) induces the type of processing in a learner except when instructed otherwise.

Dekeyer (2001) attempted to use the notion of individual representational preferences to explain the mechanism of the incongruence between students' learning strategies and instructional strategies in connection with knowledge construction. Accordingly, some students have preference for verbal stimuli (Vs) whereas others have non-verbal preference (NVs). On the assumption that a learner's preference for a processing system induces the learner to process stimuli in the preferred way, the Vs who prefer verbal stimuli tend to process verbal and non-verbal stimuli in a verbal way and translate non-verbal stimuli to verbal information. In contrast, the NVs tend to process texts by generating mental pictures.

The notion of individual representational preferences is relevant to data analysis and interpretation in this research. As we shall see in Chapter 6, the two teachers from School C repeatedly highlighted the importance of considering students' individual learning styles when interpreting whether *BioLogica* could support their learning. This notion also helps to explain the development of genetics reasoning in some students in Schools A, C and D (see Chapter 8). As such, the first function of MERs in providing complementary information and processes can cater for the differences in students' individual representational preferences (see section 2.3.7.1).

### 2.3.10 Learning Genetics with Computers: Some Programs

Biology teachers and biology educators are increasingly using technology to supplement their biology teaching and learning (Simon, 2001). Indeed, a variety of computer programs have been used in schools over the past two decades to enhance student learning of genetics.

Several well documented examples of educational software for teaching and learning genetics are worthy of mention: *Catlab* (Kinnear, 1986; Simmons & Lunetta, 1987), *Mendel* (Stewart, Hafner, & Dale, 1990), and *Genetics Construction Kit (GCK)* (Jungck & Calley, 1985). Of these, the GCK has been reported in recent research literature on genetics problem solving (Hewson & Lemberger, 2000). However, none of these programs utilise multiple representations to support learning in ways as does a new genre of educational software called a *hypermodel* (Horwitz & Tinker, 2001). *BioLogica* (Concord Consortium, 2001), an exemplar of the hypermodel software, is an interactive multimedia program for learning introductory genetics in this research. Created by object-oriented programming languages, the hypermodel multimedia programs are not only interactive but also highly visual-graphical. With dynamically linked multiple representations, the hypermodel multimedia programs promise to provide new learning opportunities for high school students.

### 2.3.11 Learning with MERs of *BioLogica*

A research study on genetics teaching and learning using an open-ended educational software program called *GenScope* (Horwitz, 1999; Horwitz & Christie, 2000; Kindfield & Hickey, 1999) indicated that students using *GenScope* software did better in their genetics reasoning than did those in the control classes but there were unanswered questions. For example, students were unable to transfer their learning to paper-and-pencil tests. Such findings informed Horwitz and his co-workers in creating *BioLogica* (Concord Consortium, 2001), a new version of the software *GenScope* reprogrammed in *Java* programming language (Horwitz & Tinker, 2001).

#### *2.3.11.1 The Software*

As the *Teacher's Guide* (Concord Consortium, 2002) describes, *BioLogica* is a multilevel courseware for introductory genetics. All the levels—Organism Level, Cell Level, Chromosome Level and Molecular Level—are linked so that changes in one level are reflected in all the other levels (see Figure 2.12).

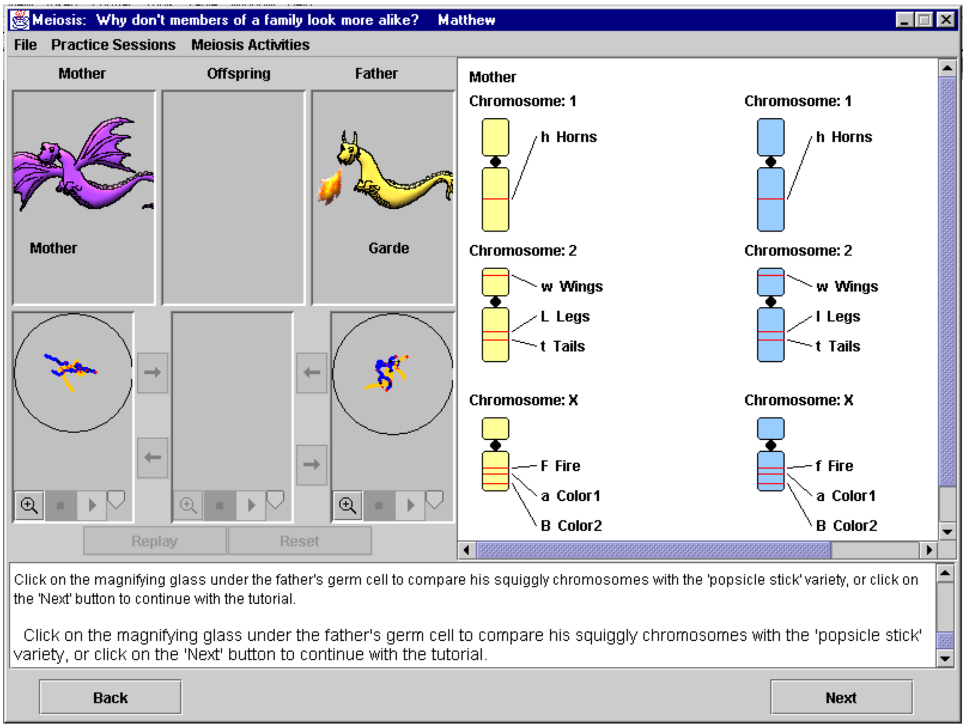



*Figure 2.12* Snapshot of *BioLogica* activity *Meiosis* showing Organism Level, Cell Level and Chromosome Level.

The *BioLogica* activities guide learners through a sequence of challenges and monitor their progress, offering them helpful hints. Whereas Levels in *BioLogica* are the organisational areas of the biological organism, Views are the pages in the software that represent the levels as well as tools used in genetics: Pedigree View (Population Level)[12], Phenotype View (Organism Level), Meiosis View (Cell Level), Gene/Allele View (Chromosome Level) and DNA View (Molecular Level) (Figure 2.12). For each View, there are Tools for the user to manipulate the graphic objects (see the Pedigree View and the Tools in Figure 2.13).

[12] This Level was not yet named in the *Teacher's Guide* (Concord Consortium, 2002) but this Level, originally present in *GenScope*, was being developed by the Concord Consortium as part of the Modelling Across the Curriculum Project (http://concord.org).

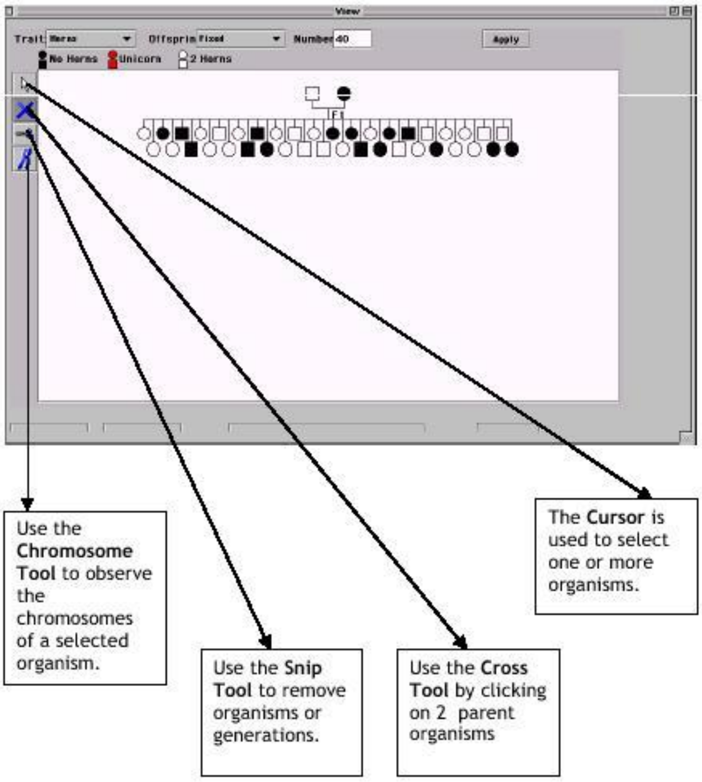



*Figure 2.13* Snapshot of *BioLogica* activity showing the Pedigree View with four Tools for manipulation (Concord Consortium, 2002, p. 6, an uncaptioned figure).

According to Horwitz and Tinker (2001), the major change in *BioLogica* is that the software is *scripted*, that is, the program provides a student user with scaffolding in the form of script or text to guide and support his/her use of the activities. The *BioLogica* program can also control the flow of a student's activity by changing from one view to another in response to his/her actions. The program can communicate with the student through graphics and text as he/she clicks on the objects on the screen. It also controls the collection and storage of data—the log files tracking the student's actions—, which are useful for analysis by a researcher. For example, in the *BioLogica* activity *Monohybrid* (see Figure 2.14), a student first predicts the offspring phenotypes, does a simulation of a cross, visualises the process and results, and then explains his/her reasoning on the screen. The student is then presented with challenges and some embedded assessment questions and real-world human genetics problems to solve.

In 2001, the Concord Consortium completed a *BioLogica* trial study in six US schools involving more than 700 students. Preliminary findings informed the software designers of the need to improve the interventions and assessments embedded in *BioLogica*, and the specifications for collecting and analysing data log files that tracked student-computer interactions (Christie & Buckley, 2001; Concord Consortium, 2001).

### *2.3.11.2 Students' Interactions with BioLogica MERs*

Ainsworth's (1999) functional taxonomy has provided a comprehensive framework for analysing the functions of the MERs in *BioLogica* or other multimedia. The taxonomy does not, however, address how a learner interacts with the MERs and how the MERs make connection to the learner's knowledge.

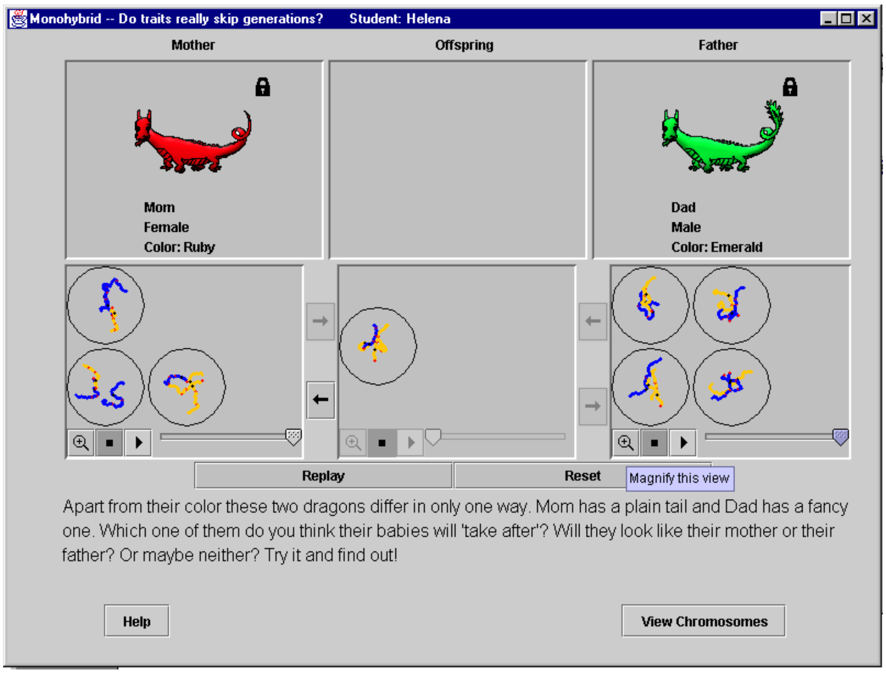



*Figure 2.14* Snapshot of the *BioLogica* activity *Monohybrid* showing a Meiosis View for Breeding a baby Dragon with a particular tail.

This study focused on the students' conceptual understanding when they learnt with MERs rather than on how exactly learners accessed these representations and their perceptual interactions with these MERs. In the naturalistic case studies reported in this thesis, the MERs of *BioLogica* play only a part in the students' classroom learning. However, when the data log files tracking students' interactions with the MERs were available, particularly in Case Study Four in School D, the analyses of log files were used to explore how the students interacted with the MERs while they were engaged in the *BioLogica* activities. Although the results of the log file analysis of Christie and Buckley (2001) posted on the Internet were only preliminary, their methods are useful to my analyses and interpretations in the results chapters (see Chapters 4 and 7). The advice given to me in an e-mail message of Buckley (personal communication, November, 8, 2001) about the *index of interaction* was also a useful source of reference and guidance in analysing and interpreting log files in this study.

### 2.3.12 Computers as Mindtools: Role of Mindfulness

As discussed in the second part of this chapter, the study examined the motivational or social/affective dimension that may influence student engagement in *BioLogica* activities and how the motivational aspect could possibly contribute to cognitive learning. In particular, I explored the role of *mindfulness* (Salomon & Globerson, 1987) on students' learning when they were regularly engaged in *BioLogica* activities as in Case Study Four.

Mindfulness is defined by Salomon and Globerson (1987) as the "volitional, metacognitively guided employment of non-automatic, usually effortful processes" (p. 623). As Jonassen (2000) argued, "[m]indfulness is required for meaningful learning, learning that is applicable to similar situations and transferable to dissimilar situations" (p. 273). Using a Vygotskian perspective adopted by Davidson and Sternberg (1985), this is also related to how well students can transfer their *competence* (genetics reasoning they developed from the computer-based multiple representations) to *performance* (solving problems in their tests).

The preceding review provided some theoretical background for Case Study Four when I explored the role of mindfulness in students' development of genetics reasoning when they regularly interacted with the MERs of *BioLogica* (see Chapter 7).

### 2.3.13 Multiple Representations and Conceptual Change

Appropriate multiple representations of a scientific conception, externally in discourse, make that conception potentially intelligible so that learners can internally represent it in their thinking (i.e., mental models) and then make it more likely for learners to judge it to be plausible and then fruitful. For a conceptually and linguistically difficult topic like genetics, talking genetics is not easy. It follows that the use of multiple representations to increase intelligibility is the first step in conceptual teaching and learning without which there will not be plausibility, or fruitfulness. However, the impact of multiple representations on epistemological and ontological aspects of conceptual change should not be overlooked.

The analysis of different representations of a scientific conception in the classroom is therefore useful for planning how to make the conception more intelligible, for interpreting classroom discourse, evaluating students' work, or reflecting by students and teacher on their own understandings (Thorley & Stofflett, 1996). In the results chapters, I will refer to the some specific aspects of the literature when I analyse and interpret the data.

## 2.4 Synopsis

The last section of this chapter summarises the three parts and attempts to synergise them into a coherent whole with which I intend to construct a theoretical bedrock for the following seven chapters.

In the first part of this chapter, I have portrayed how scientists reasoned and developed theories and models of genetics. Then, I have reviewed how researchers, science educators, and teachers similarly endeavoured to improve teaching of science in general and genetics in particular in schools. It follows that science education can be likened to the reconstruction of the products of the modelling in science and that learning in general can be regarded as mental modelling (Duit & Glynn, 1996). Whereas the second part focused on the major thinking of the conceptual change model (CCM) and some research studies, the third part of this chapter reviewed the theoretical and empirical aspects of past research with a major focus on the use of multiple representations in learning science. The review has brought together perspectives—from cognitive/computational sciences, educational psychology, linguistics, social semiotics, philosophy of science and conceptual change models in science education—for providing a framework for analysing and interpreting the data in this study.

Smith (1991) proposed two criteria for understanding in science: "connectedness and usefulness in social contexts" (p. 46), which appear to be conceptually appealing for and relevant to my purpose of synthesis of the three parts in this chapter. The first criterion for understanding is theoretically expounded by Ausubel's (1968) meaningful learning and its interpretation and extension by Novak (1990; 1998; Novak & Gowin, 1984). The usefulness in social contexts fits into the learning for conceptual change in terms of the status of the learner's conception being intelligible, plausible, and fruitful—the hallmark of all conceptual learning (Hewson & Lemberger, 2000; Hewson & Hewson, 1992; Thorley, 1990). Multiple representations—in various modalities of representation and different combinations of deployment—converge in the three functions: to complement, to constrain, and to construct (Ainsworth, 1999). MERs provide the pedagogical tools to engender conceptual change in science education grounded in these two criteria of understanding: connectedness and usefulness in social contexts. Furthermore, the conceptual change examined in this study goes beyond an epistemological dimension towards a multidimensional change. The Vygotskian perspective is an important foundation for the social/affective dimension of conceptual learning. The emphasis of this study on the relationship between of motivational aspects of learning and genetics reasoning is also related to intentional conceptual change which is an emergent direction of research in science education.

This synopsis is intended to inform the analysis and explanation of the data about students' conceptual learning of genetics with the MERs of *BioLogica*. Multiple representations hold promise to engender interest, motivation and conceptual understanding of genetics. On the basis of this synopsis, I will present in the next chapter the methodology and methods about how I conducted the four case studies in this research.

# Chapter 3

# Methodology and Methods

## 3.0 Overview

Chapter 3 presents the research methodology and the general research methods which I utilised in this doctoral study in six Years 10 and 12 classes across four different schools. In differentiating between the meaning of *methodology* and *methods*, the qualitative research tradition looks at methodology as a way of thinking about and studying social reality (e.g., classroom learning) whereas methods or research methods are a set of procedures and techniques for gathering and analysing data in that reality (Strauss & Corbin, 1998). As the school and classroom contexts in this research varied from one case study to another, the more specific methods will be discussed in each of the results Chapters 4, 5, 6, and 7.

In section 3.1, I will introduce my own theoretical orientations in relation to positivism and qualitative research methodology. Sections 3.2 to 3.4 are about the qualitative research methodology and its theoretical underpinnings used in this study. This is then followed by section 3.5 which discusses the initial research questions based on which case-specific research questions were later reformulated in the following four case studies (see Chapters 4 to 7). Section 3.6 is about the four basic data collection methods—testing students online, interviewing teachers and students, observing lessons, and gathering documents and artefacts—which when implemented, were again slightly different in the four case schools in responding to the case-specific research questions. Section 3.7 is about within-case and cross-case data analyses and interpretations. The next two sections are about validity, reliability, objectivity and ethics in the qualitative research tradition. Finally, section 3.10 discusses the limitations of the methodology and research methods in this study. Throughout this chapter, I have attempted to disclose, alongside the methodology and methods, my progressively focused thoughts, and my reflections to conform to the genre of qualitative research writing.

## 3.1 My Theoretical Orientations

Educated in biology and chemistry for my first degree in Hong Kong, I had been a dedicated biology and science teacher during my two decades of classroom teaching. I subscribed to Posner et al.'s (1982) metaphor of *student as scientist* without actually reading their work at that time and I considered the school is where students seek the truth of knowledge and science. However, there was some ferment for change back in my mind. During my undergraduate university days, I had taken a few elective courses in psychology, sociology, and history besides the computer programming courses I mentioned in Chapter 1. I also had a compulsory four-year general studies program[13] on philosophy as part of my undergraduate study. I have also been a voracious reader of books from diverse domains.

Once I believed in the positivist research orientation that the reality in schools, classrooms and individuals is, as Merriam (1998) put it, "stable, observable and measurable" (p. 4) by scientific and experimental research. My conception about research in education was soon to change. I came to see that qualitative research allows the researcher to explore research questions in classroom learning that cannot be answered fully or satisfactorily by quantitative methods with an experimental-control group design. Overall, my theoretical perspectives in this research were largely in the postpositivist arena. Furthermore, my keen interest in language and linguistics and my knowledge about the French, Japanese and German language have always predisposed me to prefer using semiotic and sociolinguistic perspectives about human learning in some parts of this study.

## 3.2 Qualitative Research

Merriam (1998) listed five characteristics of qualitative research which is "an umbrella concept covering several forms of inquiry that help us to understand and explain the meaning of social phenomena with as little disruption of the natural setting as possible" (p. 5):

[13] When I was studying in Chung Chi College, the Chinese University of Hong Kong in the 1970s, every undergraduate had to take a four-year general education program entitled the *Integrative Basic Studies (IBS)* about philosophy of Confucius, Plato, Socrates, Karl Marx, Sigmund Freud, Paul Tillich and the *Bible*— philosophers and their works that had major impacts on human thinking.

(1) to understand the phenomenon of interest from the participant's perspective (emic) but not the researcher's (etic);
(2) to use the researcher as the primary instrument for data collection and analysis;
(3) to do research is to involve fieldwork, i.e., "the researcher must physically go to the people, setting, site, institution (the field) in order to observe behaviour in the natural setting" (p. 7);
(4) to employ an inductive research strategy, i.e., "builds abstractions, concepts, hypotheses, or theories rather than tests existing theory" (p. 7); and
(5) to focus on process, meaning and understanding, and "the product of a qualitative study is richly descriptive" (p. 8).

Given the complexity of classroom learning of genetics when the teachers included computer-based multiple representations in their teaching, qualitative research appears appropriate for this study. When I first conceptualised the proposal for this study, I found that the interpretive research approach (Erickson, 1986, 1998; Gallagher, 1991) with a case-based research design (Merriam, 1998; Yin, 1994), was most suitable. However, as recommended by Fraser and Tobin (1991; 1998), when quantitative methods (e.g., analysis of questionnaire and test data) and qualitative methods (e.g., analysis non-numerical data from interviews, observations or documents) are combined, more meaningful interpretation of the data can often be achieved. It was along this line of thinking that I used the interpretive case-based research that was largely qualitative but the research also included some quantitative data analysis and interpretation.

## 3.3 Interpretive Research

Interpretive research is a methodology rooted in phenomenology which is concerned with understanding of human behaviour from the participants' own frame of reference. Interpretive research attempts to interpret and understand the meaning-perspectives of the participants, i.e., teachers and students in the classroom, in the search for patterns of meanings-in-action and for building up new theories (Patton, 1990). In this study, qualitative data (interviews and other verbal data) and some quantitative data (test scores) were analysed and interpreted using the interpretive research methods. Qualitative methodologies and methods generally followed the qualitative research traditions of the various authors in Denzin and Lincoln's (1994) handbook and those case study methods of Yin (1994), Stake (1995) and Merriam (1988; 1998) but some more specific methods were used such as Lemke's (1990; 1998a) discourse analysis.

Carr and Kemmis (1986) abstracted a plethora of educational research approaches into three basic orientations: *positivist*, *interpretive*, and *critical*. Interpretive researchers consider education as a process and school as a lived experience. The knowledge gained from the research involves the understanding of this experience with multiple realities constructed socially by individuals. According to Erickson (1986), interpretive research encompasses approaches that includes *ethnographic, qualitative*, *participant observational, case study*, *phenomenological*, *symbolic interactionist*, and *constructivist* research. Interpretive research, formerly not an accepted methodology in science education, has, over the past 20 years, gained international popularity, prestige and respectability. It has also helped science educators and policy makers to better understand schooling in science as well as the limitations of traditional research methods. Indeed, Gallagher's (1991) *NARST Monograph* entitled *Interpretive Research in Science Education* has made this methodology increasingly popular amongst researchers in science education. According to White's (1997) analysis of the major changes in the trends in research in science education over the three decades from the 1970s to the 1990s, one major trend was that more published journal articles had been about lengthy observations and descriptions of classroom than those about brief, well-designed and controlled laboratory style experiments. There were also more studies which utilised interviews as data sources than those which relied on inferential statistics.

This research aims at exploring students' conceptual change when the instruction included the use of computer-based multiple representations (see Chapter 2) in classroom teaching and learning of genetics. *BioLogica* (Concord Consortium, 2001), an interactive multimedia program that features multiple representations, was involved in all the six classrooms in the four case studies alongside with teachers' other representations which they used in their teaching. In Case Study Three in School C, teachers used some other online multimedia as well. The research adopted an interpretive research approach (Erickson, 1986, 1998; Gallagher, 1991) with a case-based design (Merriam, 1988; Yin, 1994).

Whereas the overarching theoretical framework for interpreting student learning is the multidimensional conceptual change model (Tyson et al., 1997), the case-based interpretive methodology also included a number of other perspectives, particularly the computational perspectives (Thagard, 1988), multilevel thinking from the cognitive science (Johnstone, 1991) and discourse analysis from semiotics (Lemke, 1990, 1998a) (see section 2.3.4). Multiple methods, multiple data sources, multiple perspectives, and multiple-case design are intended to enable the researcher to generate assertions to be confirmed or disconfirmed respectively through *triangulations* (Denzin & Lincoln, 1994; Denzin, 1989; Erickson, 1986; Merriam, 1998) (see section 3.6).

## 3.4 Case Study Methodology

In education, case study research is generally synonymous with a variety of qualitative research approaches, such as *fieldwork*, *ethnography*, *participant observation*, *naturalistic inquiry*, *grounded theory*, or *exploratory research* (Merriam, 1998). Despite the terms being synonyms, they represent methods with different emphases in the research focus. I will explain some of these methods when they occur in the later parts of the thesis.

According to Yin (1994), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident" (p. 13). By drawing on a number of case study researchers' ideas (Miles & Huberman, 1994; Stake, 1995), Merriam (1998), who previously conceptualised a case study as being its end product only, concluded that the most defining characteristic of case study research lies in delimiting the object of study, the case:

> …the case as a thing, a single entity, a unit around which there are boundaries. I can 'fence in' what I am going to study. The case then, could be a person such as a student, a teacher, a principal; a program; a group such as a class, a school, a community; a specific policy; and so on. (p. 27)

A case study is characterised by three major features (Merriam, 1998). First, a case study is *particularistic* in that it focuses on a particular situation, event, program, or phenomenon. Second, the case study is *descriptive* in that its end product is “a rich, ‘thick’ description” (p. 29) of the phenomenon being studied. Thick description, which is usually qualitative, means “the complete, literal description of the incident or entity being investigated” (pp. 28-29). Such description is often supported by direct quotes from transcripts or documents and other qualitative data. Third, a case study is *heuristic* in that it illuminates readers’ understanding of the phenomenon being studied by providing some new insights or extending their experience about the phenomenon.

In this study, there were four case schools. Unlike a holistic case of which only the global nature is considered, there were within each case school subunits such as classes, and within these subunits, there were further subunits such as teachers and students. This design in this research was therefore similar to Yin’s (1994) multiple-case embedded design using multiple units of analysis. Yin recommended this research design for studying school innovations (e.g., the use of new technology) in which independent innovations occur at different sites. As such, I found that Yin’s multiple-case embedded design was most suitable for this research although the conduct of such a study was costly in terms of time and energy. Eventually, I conducted my studies in three state co-educational senior high schools and one independent (private) girls’ school. The four case studies involved five teachers (with teaching experiences ranging from 0 to 27 years), and six classes (four Year 10 Science, one Year 12 Biology and one Year 12 Human Biology). It was known in 2003 that the four case schools represented a range of schools with students having differing abilities in terms of examination results as indicated by the statistics published by the Curriculum Council of Western Australia (Hewitt, 2003) (see Chapter 8).

Perhaps it is useful to clarify here the meaning of two methods said to be synonymous with case study at the beginning of this section. The first one is about *naturalistic inquiry*. As Lincoln and Guba (1985) put it, naturalistic inquiry is “what the naturalistic investigator does… What is salient to us is that, first, no manipulation on the part of the inquirer is implied, and, second, the inquirer imposes no *a priori* units on the outcome” (p. 8). In this research, the first case study was done in almost a naturalistic situation. However, in the last case study, the high degree of collaboration with the teacher in School D—with a common aim to support the students with low prior knowledge—involved some intervention and was not so naturalistic as such. Second, *grounded theory* is important throughout the four case studies. The term grounded theory first proposed by Glaser and Strauss (1967), has been a powerful way of analysing and interpreting data towards building theory from it. As Strauss and Corbin (1998) explained, grounded theory means "theory that was derived from data, systematically gathered and analysed through the research process. In this method, data collection, analysis, and eventual theory stand in close relationship to one another." (p. 12). In this context, a theory is "[a] set of well-developed concepts related through statements of relationship, which together constitute an integrated framework that can be used to explain or predict phenomena" (Strauss & Corbin, 1998, p. 15).

## 3.5 Research Questions

As Merriam (1988) explained, "[a] qualitative design is emergent: One does not know whom to interview, what to ask, or where to look next without analysing data as they are collected…" (p. 123). Similarly, Stake (1995) argued that case study work needs to be *progressively focused*, that is, "the organising concepts change somewhat as the study moves along" (p. 133). As such, the initial research questions had undergone some refinements and reformulations as the research moved on from the first case study through the following three cases studies.

The two broad research foci, originally framed with the research questions subsumed within each, were written in a more specific manner:

Focus 1. The extent to which the teacher-designed classroom learning environment —using the multimedia *BioLogica* and other teaching resources—is conducive to students' development of higher order learning in genetics.

Research questions:

1. How do teachers integrate *BioLogica* into their classroom teaching and learning of genetics?
2. What are teachers' beliefs, referents and actions in the integration and implementation of *BioLogica*?

3. How effective is the learning environment in engendering students' reasoning in genetics?

Focus 2: Students' interactions with the multiple representations in *BioLogica* and other teaching material when learning to develop reasoning in genetics.

Research Questions:

4. What actors affect students' interactions with the multiple representations in the multimedia program?
5. In what ways do their students' interactions with these multiple representations contribute to their higher order learning?
6. Do the computer-based multiple representations bring about students' conceptual change in their understanding of genetics concepts?

While collecting, analysing and interpreting the data in School A, I came to identify some issues and posed some new questions. As such, the six research questions above soon appeared not as relevant as originally conceptualised. They were soon reformulated to the six initial research questions (RQ1 to RQ6) as follows:

RQ1. How does the teacher integrate and implement *BioLogica* in his/her classroom teaching of genetics?

RQ2. What are the teacher's beliefs, referents and actions in the integration and implementation of *BioLogica*?

RQ3. What are the major barriers to using *BioLogica* activities in classroom teaching?

RQ4. What are the factors from the social/affective perspective that influence students' interaction with *BioLogica* in their conceptual learning of genetics?

RQ5. Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? If so, to what extent and in which types of genetics reasoning?

RQ6. What are the students' gene conceptions before and after the lessons that include *BioLogica*?

Research questions 1 to 3 were subsumed under first focus whereas research questions 4 to 6 were under the second focus. Research questions 4 to 6 also correspond respectively to conceptual learning along the social/affective, epistemological and ontological dimensions of the multidimensional conceptual change model (Tyson et al., 1997).

While the research was ongoing, I continuously revisited the literature, had conversations with my colleagues and other researchers. Feedback from critical others and my own reflections continued to shape my thinking about the research questions and data collection methods to seek the responses to these questions. Some classroom realities often turned out to be different from what I had expected before the case studies started. The findings of the previous case study or studies also informed the next case study design. As such, these six initial research questions were further refined in light of the findings of the previous case study or studies. The rationale for the reformulation of the research questions to suit the classroom context of each case study will be respectively discussed in the Chapters 4, 5, 6 and 7 about the four case studies. In Chapters 9, I will discuss the synopsis of the findings by revisiting the six initial research questions and some case-specific research questions to draw conclusions of the study as a whole.

## 3.6 Data Collection Methods

As I mentioned briefly in the preceding sections, three of the four methods of collecting data in this research—interviewing, observing and collecting documents and artefacts—are often used in interpretive and case study research because "no single sources of information can be trusted to provide a comprehensive perspective…By using a combination of observations, interviewing, and document analysis, the fieldworker is able to use different data sources to validate and cross-checking findings" (Patton, 1990, p. 244). Besides, some quantitative data (e.g., scores of students in researcher's and teacher's tests) were collected to enrich data analysis and interpretations.

### 3.6.1 Online Tests

The major criteria for higher order learning in genetics were the six types of reasoning encompassing both the domain-general and domain-specific dimensions (see Table 3.1) for assessing *GenScope* learning environment (Hickey & Kindfield, 1999). As reviewed in Chapter 2, *GenScope* was a predecessor computer program of *BioLogica* (see section 2.3.11).

The researcher-designed online tests were sources of quantitative and qualitative data about the learning outcomes of the students. The online tests, pretests and posttests, consisted of two-tier multiple choice items (Treagust, 1988) which gauged the students' genetics reasoning and some open-ended questionnaire items elicited students' gene conceptions and perceptions about their learning. In each case school, all the students were given a password and an account to log on to the website which I developed on the server of Curtin University to take the online tests before and after the teaching and learning of genetics (see Appendix 2, Figure A2.1.1). Only the data of the participating students were used in the research.

Two-tier multiple choice items, as indicated by a number research studies, are an reliable instrument in diagnosing students' preconceptions or alternative conceptions (Haslam & Treagust, 1987; Odom & Barrow, 1995). In a two-tier test, the first tier is about the content knowledge, and the second tier, or the reason of the choice in the first tier, is about the understanding of that knowledge (Odom & Barrow, 1995). As Treagust (1988) pointed out, the analysis of the a two-tier test results help the teacher to identify students' preconceptions or alternative conceptions with ease and can subsequently address them in their teaching. Nevertheless, Griffard and Wandersee (2001) could not replicate Haslam and Treagust's results using the two-tier instruments about photosynthesis but their sample ($n$ = 6) was too small and the contexts of the two studies were different.

The online pretest served three purposes: (1) to inform the classroom teachers of the students' alternative conceptions or the amount of their prior knowledge about genetics; (2) to inform the researcher of the baseline knowledge of the participating students’ prior knowledge for posttest construction; (3) to identify some foci for probing further during the preinstructional interviews of the participants.

Table 3.1

*Six Types of Genetics Reasoning adapted from Hickey and Kindfield (1999)*

| Domain-Specific Dimension of Reasoning (simple ↔ complex) | | Domain-General Dimension of Reasoning (Novice ↔ Expert): Cause-to-effect Reasoning | Effect-to-cause Reasoning | Process Reasoning |
|---|---|---|---|---|
| complex | Between-generations | Monohybrid Inheritance:<br>Mapping Genotype to Phenotype<br>(Type II) | Monohybrid Inheritance:<br>Mapping Phenotype to Genotype<br>(Type IV) | Punnett squares (input/output reasoning):<br>Meiosis process (event reasoning.<br>Mitosis process [a]<br>(Type VI) |
| simple | Within-generations | Mapping Genotype to Phenotype<br>(Type I) | Mapping Phenotype to Genotype<br>(Type III) | Mapping information in DNA base sequence (genotype) to amino acid sequence in protein synthesis (phenotype)[b]<br>(Type V) |

[a] Not included in Hickey and Kindfield’s (1999) original types.

[b] Not included in Hickey and Kindfield’s (1999) original types but adapted from Venville and Treagust’s (1998) sophisticated conception of genes as being *a productive sequence of instructions*.

The pretest two-tier items and open-ended questionnaire items on genetics were constructed based on the previous research on genetics education (Hackling & Treagust, 1984; Venville & Treagust, 1998). References were also made to Western Australian textbooks and biology/science curriculum documents, and the Tertiary Entrance Examinations (TEE) Biology and Human Biology papers and examiners’ reports. The draft of the pretest was reviewed by two university lecturers and two experienced science teachers and revised several times for improvement. The final version of the pretest for the first case study contained three open-ended questionnaire items and 11 two-tier items. The format and difficulty level of the posttest basically followed the pretest design. Based on the suggestion of Mr Anderson, the participating teacher in School A, I reduced the number of items to allow students more time to think about each item during the online test. The final version of the posttest contained three open-ended and eight two-tier items of which six are parallel items (one item in Types I, III and IV, and three in Type VI). Parallel items allow for pretest-posttest comparison of genetics reasoning according to Hickey and Kindfield's (1999) reasoning types as shown in Table 3.1 (see Appendix 2, Figure A2.4.1 to A2.4.6, for a sample of each type). The improved draft of the online tests were trialled by a student teacher in one Western Australian university and her feedback informed me to further improve the draft before the tests were used in School A. The participating student teacher later became the participating preservice teacher of School B in the second case study (see Chapter 5).

As the study progressed, changes were made to the original online tests. For Case Study Two, the posttest only was delivered to students to do it at home (see Chapter 5). In Case Study Three (School C), three more parallel items were added to the pretest and posttest so that there was at least one item for each of the six genetics reasoning types. One open-ended questionnaire item asked students to self-report their usage of the *BioLogica* activities with their laptop computers because very few log files were collected (see Table 3.2).

Table 3.2

*Checklist of Common Online Test Items Across Four Case Schools*

| Online Test | Case School | Number of Two-tier Items in each Genetics Reasoning Type | | | | | | Total Number of Parallel Items |
|---|---|---|---|---|---|---|---|---|
| | | Type I | Type II | Type III | Type IV | Type V | Type VI | |
| Pretest and Posttest | A | 1 | Nil | 1 | 1 | nil | 3 (2+1[a]) | 6 |
| | B [b] | 1 | Nil | 1 | nil | nil | 3 (2+1[a]) | 5 |
| | C | 1 | 1[d] | 1 | 1 | 1[c] | 3 (2+1[a]) | 8 |
| | D [d] | 2 (1 + 1[e]) | 2 (1 + 1[e]) | 2 (1 + 1[e]) | 2 (1 + 1[e]) | 2 (1[c]+ 1[e]) | 3 (2 + 1[e]) | 12 |
| Common items (Schools A, C and D or all) | | 1 | Nil | 1 | 1 | nil | 2 | 5 |

[b] In School B (Case Study Two), Only one online test at the end of teaching was given to students.

[a] Items common to tests for Schools A, B, and C only.

[c] Items common to tests for Schools C and D only.

[d] The posttest for School D provided feedback to students for any option in each item they chose.

[e] Item in tests for School D only.

In Case Study Four (School D), six more parallel items including two items modified from interview tasks were added to the online tests so that there were two parallel items of Types I to V genetics reasoning and three of Type VI. The open-ended questionnaire items about students' perceptions were deleted to allow the students to complete the online tests in 30 minutes as in the previous case schools. The unique feature of the posttest for School D was the online feedback provided to students for any option which they might choose in the two-tier items. Despite these changes, there were five parallel two-tier items common to all the online tests across the four case studies for comparison (see Table 3.2).

The scoring of the online test two-tier items in this research followed an all-or-none rule in that a student was awarded two marks if both the first tier (content knowledge) and the second tier (reason for the first tier) were correct or none if one of them was wrong. With this stringent standard of scoring, the chances of obtaining high scores by guessing were very low.

As for the open-ended questionnaire items in the online tests in Case Studies A, C and D, parallel items were asked about the gene conceptions and their perceptions about learning genetics. The pretest-posttest verbal data in these open-ended questionnaire items were compared and contrasted to assess the preinstructional-postinstructional learning outcomes.

### 3.6.2 Interviews

Interviewing participants was the major method of data collection in this study. Patton (1990) clearly explained the purpose of interviews:

> We interview people to find out from them things we cannot observe…feelings, thoughts, and intentions…behaviours that took place at some previous point in time...situation that preclude the presence of an observer…how people organised the world and the meanings they attach to what goes on in the world-we ask people questions about those things. (p. 278)

The student interviews aim at probing the students' conceptual understanding of genetics in terms of reasoning, their interest and motivation in learning genetics when the teacher included in their teaching the computer activities of *BioLogica*. As reviewed in Chapter 2, I looked at student learning along three dimensions: epistemological (genetics reasoning), social/affective (interest and motivation) and ontological (gene conceptions). Interviews of some selected students allowed me to probe deeper into their learning along these dimensions. The teacher interviews focused on the teacher’s beliefs, expectations, perceptions and reflections before and after their teaching of genetics that included *BioLogica*.

As the students might not have much free time during a school day and had other commitments during their free time, the preinstructional interview was done in about 20 to 30 minutes or in some special cases, two to three times of 10-minute intervals to complete the interview. The postinstructional interviews were conducted likewise. I always ensured that the student interviewees were willing to take part and felt comfortable being interviewed.

#### *3.6.2.1 Student Interviewees Sample*

The students were selected for interviews by purposeful or theoretical sampling (Patton, 1990). As Glaser and Strauss (1967) explained, “theoretical sampling is the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyse his data and decides what data to collect next and where to find them in order to develop this theory as it merges” (p. 45). From each class in each case study, two to four target students (including both genders in co-educational schools) whom I called target interviewees, were selected based on their pretest results and the referral of the teacher across a range of abilities. All interviewees were protected by pseudonyms to preserve their anonymity and confidentiality. As the case study progressed, the peers of the target students in Schools A and C were also invited to take part in the postinstructional interviews. The discussions in the interviews often became more interactive and the students had more to say than if the interviewee was alone with the interviewer.

#### *3.6.2.2 Interview Protocols*

As the purpose of the interview is “find out what is in and on someone else’s mind.” (Patton, 1990, p. 278), I used interviews to explore the ontological and social/affective dimensions of the students’ conceptual understanding in genetics. The analysis of interview data provided a more in-depth understanding of the students’ conceptual change in terms of the status of their new conceptions of genetics. It is also from this analysis that I attempted to seek responses to the initial research questions 4, 5 and 6 (see section 3.3) regarding the effects of the use of multiple representations on the students' learning. For the teacher interviews, the questions sought answers to the initial research questions 1, 2 and 3 (see section 3.3). However, as the contexts in the case schools were different, the questions in the teacher interview protocols varied slightly as some specific research questions were different.

According to Merriam (1998), the interviews are semi-structured when they have a protocol with a set of questions and issues to be explored; however, the exact wording and order of these questions is not predetermined but depends on the interaction between the interviewer and the respondent as the interview progresses. The student interviews had three foci. The first focus was on students' gene conceptions before and after instruction. The second focus was on a reasoning task on pedigree analysis. This part will follow the techniques for *interview-about-instances* and *interview-about-events* (Bell, Osborne, & Tasker, 1985; White & Gunstone, 1992). Like the two-tier tests, the interview reasoning tasks involved the six type of genetics reasoning (Hickey & Kindfield, 1999). The third focus was on the students' perceptions of their experiences of learning genetics, including the use of *BioLogica*. However, not all the three foci were used in the interviews. In Case Study Four, as the participating students were Year 12 students who were very busy preparing for the Tertiary Entrance Examination (TEE), I omitted the second focus about genetics reasoning in the only student interview; rather the interview reasoning tasks were incorporated in the online tests. The protocol for the teacher interview also varied according to the school context and teacher's interest in the topic discussed. In the postinstructional teacher interview, I always asked the teachers about their experiences using *BioLogica* and asked them to reflect on what they had expected (see Appendix 3, Documents A3.4.3 and A3.4.4 for a sample of interview protocols).

#### *3.6.2.3 Asking Good Questions*

As Merriam (1988) suggested, the interviewer needs to be "neutral and non-judgemental no matter how much a respondent's revelation violates the interviewer's own standards" and to "refrain from arguing, sensitive to the verbal and non-verbal message being conveyed" and "is a good reflective listener" (p. 75). Therefore, in designing the interview protocols, I tried to use some of Merriam's (1998) four types of good questions: (1) “Hypothetical questions”, (2) “Devil’s advocate questions”, (3) “Ideal position questions”; and (4) “Interpretive questions” (p. 77) and tried to avoid using “multiple questions”, “leading questions”, and “Yes-or-No: questions” (p. 79). However, I found that the use of some leading questions based on previous case study findings were sometimes justified and the yes-or-no questions, too, were useful as a starter in the interview and when such use was based on what was discussed in a previous interview. A *yes-or-no* question may be followed up by a *why* question to probe further.

#### *3.6.2.4 Analysis and Interpretation of Verbal Data*

Like the online tests, the interview aims to probe students’ genetics reasoning from three-dimensions: epistemological, social/affective (motivational) and ontological. The emphasis of the study was on learning in a domain-specific area with computer-based multiple representations. I found that the Chi’s (1997) verbal analysis method suitable for the analysis of the verbal data in the interview transcripts that had both qualitative and quantitative components, including perceptions, gene conceptions and reasoning tasks.

The interview tapes were transcribed verbatim by a transcriber[14] as soon as possible after the interview. When the interview transcripts were ready, I edited each transcript and clarified some points with the transcriber. I sometimes listened to the original audiotapes and compared the transcript to what was spoken in the interviews. Sometimes, when some parts appeared to be missing or incorrectly transcribed, I had to ask the transcriber to re-listen to a particular part and amend the transcript. A copy of the transcript of each teacher interview was sent to the teacher for *member-checking* (Guba & Lincoln, 1989) and then amended according to the teacher’s feedback before the transcript was analysed.

According to Chi (1997), verbal analysis is a method for quantifying the subjective or qualitative coding of the contents of verbal utterances whereby the researcher tabulates, counts and draws relations between the occurrences of different kinds of utterances to reduce the subjectiveness of qualitative coding. Unlike protocol analysis, verbal analysis focuses on capturing student’s knowledge

---

[14] The transcription of the tapes was done by one of the two helpers (see section 1.6 and footnote 2).

representation and less on the processes of problem solving. Chi's method of coding and analysing the verbal data consists of eight functional steps: (1) reducing the data; (2) segmenting them into units; (3) categorising or coding the units; (4) operationalising evidence (for coding) in the coded data; (5) depicting the coded data; (6) seeking patterns(s) and coherence; (7) interpreting the pattern(s); and (8) repeating the whole process if necessary.

As Chi (1997) explained using the conceptual change research examples, to analyse students' mental models in science, this verbal analysis method must make use of both bottom-up and top-down orientations operating in an interactive fashion. The bottom-up orientation is used by interpretive research methods in a coding process that starts with the smallest units of the protocol, e.g., by developing *in vivo categories* as they emerge from what the interviewees said as in grounded theory method (Glaser & Strauss, 1967). According to Chi, the top-down orientation entails the use of theory-driven questions and codes or a set of *a priori categories*. Although this sounds positivist, I found that Chi's method suited my analysis of the interview reasoning tasks when I coded the students' verbal data because they thought aloud to solve the problem and at the same time I had the six genetics reasoning types of Hickey and Kindfield (1999) in mind (see Chapter 4).

While analysing and interpreting the data, I endeavoured to display the data and patterns by way of visual-graphical representations using Miles and Huberman's (1994) methods (see the following chapters). In Case Study One, as I had the opportunity to interview the students for a long time about their conceptions of genes, I used concept mapping (Novak, 1990) (see section 4.4.4 [15]) to display the propositions given by the student interviewees in the preinstructional and postinstructional interviews and compare their conceptual change. However, in other case schools, this display was not used when the interview time was too short for probing students' gene conceptions in the way as I did in School A.

[15] Thereafter in the thesis, only the section number is used in cross-chapter references. For example, section 4.4.4 refers to a section in Chapter 4 and can be located using the page number of section 4.4 in the table of contents.

### 3.6.3 Classroom Observations

Another major means of collecting data in this research was classroom observations, which, unlike interviews, allowed me to observe participants' actions in their natural field setting, i.e., classroom or computer room. As Merriam (1998) explained, not only can observations provide a researcher with some knowledge of the context, specific instances and so on as reference points for subsequent interviews, the researcher can also observe things which the observed would not have been willing to talk about. For instance, in School C, after staying in the two classrooms (91% and 75% of all the lessons) over seven weeks, I had developed a very good knowledge of how the girls used the laptop computers in their daily classroom life. I could not possibly have such knowledge through interviews or document analysis. The being-in-the-classroom experiences enriched my data analyses and interpretations in the four case studies but such persistent observations were inevitably associated with tensions and ethical issues.

#### *3.6.3.1 Collecting Data in Observations*

My role in the classroom observations varied slightly from being a "spectator" (Patton, 1990, p. 206) or "complete observer" (Merriam, 1998, p. 101) in School B, to being an "observer as participant" (Merriam, 1998, p. 101) in Schools A and C. I appeared to be more like a "participant as observer" (Merriam, 1998, p. 101) in School D where the teacher collaborated closely with me and allowed me to have some co-teaching with her in supporting the students' learning with *BioLogica* (see Chapter 7).

Except for School B, where the preservice teacher taught only for three weeks, the other three case schools had genetics for about five to seven weeks. I always endeavoured to observe all the lessons when the teacher welcomed me there. For example, in School A, I spent about nine weeks in the school observing most of the lessons before and when genetics was being taught (over 6 weeks). Four lessons were videotaped and audiotaped and were then transcribed verbatim for analysis and interpretation. For every lesson observed, I wrote down as much as possible in my field notes, jotting down the exact time of certain key episodes so that I could collate my field notes with the lesson transcript. For every visit, I wrote reflective journals which very often were interwoven with the field notes. I always tried to expand these field notes and journals soon as possible after the observation while memories were fresh. In Schools C and D, classroom observations sometimes included some special foci such as observations of one or more dyads during the DNA experiment in School C or during the computer sessions in School D to address some specific research questions (see the results chapters).

#### *3.6.3.2 Simple Analysis of Classroom Discourse*

I use the word *simple* here to delineate my discourse analysis of teaching and learning in science classrooms without going into the highly technical domain of semiotics. Lemke's (1990; 1998a) methodology for using semiotic methods in analysing science classrooms was my major referent in discourse analysis.

As Shapiro (1998) argued, semiotics broadens the term *learning environment* to include a set of signs, symbols and rules about interaction that are used by students and teachers to develop knowledge, skills and attitudes in the classroom. Understanding the complex ways in which students and teachers use these signs and symbol systems provides powerful insights into the ways teachers (or other instructional media) communicate with learners in the school setting. Therefore, this approach is "particularly useful in research on school and classroom interaction" (p. 610). In Lemke's (1990) study, he used social semiotics to analysed the classroom interactions when the teachers were *talking science*.

I also draw on Lemke's (1990; 1998a) methods of data analysis of verbal data in science education research in an attempt to analyse the discourse in classroom interactions in this study. Social semiotics asks "how people use sign to construct the life of a community" (Lemke, 1990, p. 183). Accordingly, making meaning is the process of connecting things such as actions or events to contexts, i.e., making them meaningful by contextualising them. Only some basic methods of discourse analysis were used in analysing classroom interactions. For example, in Case Study Four reported in Chapter 7, the lesson transcripts (dialogic interactions between dyads) were first collated with the field notes and/or computer log files (see section 7.4). Selected episodes were then reduced and segmented using Chi's (1997) methods. Then I used some of Lemke's (1990) methods to identify the lesson activities such as Triadic Dialogue, Student-Questioning Dialogue, Teacher-Student Duolog, Teacher-

Student Debate, True Dialogue and so on. I will elaborate these activities while analysing the classroom discourse in the results chapters.

When teacher or students were explaining genetics, I used some of Ogborn et al.'s (1996) methods in the analysis of scientific explanations. Accordingly, the teachers used four of the strategies in explaining science: *creating differences*, *constructing entities*, *transforming knowledge*, and *putting meaning into matter*. Eventually, as reported in the results chapters, the five science/biology teachers, whose teaching experiences ranged from 0 to 27 years, taught and explained genetics to their students in one way or another, sometimes by referring to the *BioLogica* activities.

### 3.6.4 Collecting Data from Documents and Artefacts

Unlike interviewing and observing, collecting documents does not intrude upon or affect the settings and is easier and more convenient (Merriam, 1998). However, the reality of conducting research in schools required the collection of some local or personal documents, which still involved some intrusion into the teacher's or students' normal classroom life. Collecting such documents depended on the consent of the teachers, students and the students' parents. Even with the parents' signed consent, I had to ask participating students for their consent in allowing me to copy their work or notes. It was always easier if, after some time in the setting, I had developed some rapport and trust with the students. Sometimes, when the teachers did not support my request for some documents from the students, I always respected their advice.

In this research, the following documents or artefacts were collected for analyses and interpretations: school documents (including the year book and newsletters), the science/biology teaching syllabus, teacher's teaching schemes/plans, teachers' handouts/overhead projection transparencies, students' assignments/notes/test scripts, students' computer log files, students' mark sheets, public documents (e.g., Western Australian government reports/handbooks and newspapers etc.). Some documents or artefacts such as the computer log files (which tracked the student use of *BioLogica*) or the online records (of students' performance in the online genetics reasoning tests) can be considered as "researcher-generated documents" (Merriam, 1998, p. 118) because they had been produced for the purpose of this research study. The detailed methods of analysing the log files are given in Chapters 4 and 7 alongside the data analysis and interpretation.

## 3.7 Data Analysis and Interpretation

I have outlined the methodology and the associated methods in collecting data from multiple sources using multiple methods from multiple field sites. This section provides a summary of these methods by mapping them to the research questions of this study and discusses some important strategies in data analysis and interpretation, particularly the construction of causal networks and models for the whole study.

### 3.7.1 Matching Methods to Research Questions

The complexity of the number of components in the four major methods of collecting data from online tests, interviews, observations and documents all aimed at seeking answers to the initial research questions (see section 3.5). Table 3.3 maps the data collection methods, data sources, analyses and interpretation methods to the six initial research questions.

It must be noted that the six initial research questions in Table 3.3 were later modified or reformulated into specific research questions as the research progressed and the mapping of the methods to the research question had concomitant changes (see a similar table in each of Chapters 4 to 7). In managing and analysing the non-numerical or verbal data, I used the *NUD*IST* 4 and *NVivo* software tools (see section 1.8). As I progressed through the final analyses, I used both manual analysis and computer-based analysis. The software tools helped me to manage hundreds of documents—interview and lesson transcripts, log files and online test files—for convenient search, retrieval and comparison of data coded under particular categories.

Table 3.3

*Mapping the Research Methods to Research Questions*

| Research Question | Data Collection Method (V = verbal data; N = numerical data) | | | | Source (T for teachers; S for students) | Methodological Framework in Data Analysis and Interpretation | Chapter Section on Methodological Framework |
|---|---|---|---|---|---|---|---|
| | Online Tests | Interviews | Observations | Documents | | | |
| RQ1 How does the teacher integrate and implement *BioLogica* in his/her classroom teaching of genetics? | | V | V | V (teaching scheme, time-table, handouts etc.) | T | Interpretive framework (Gallagher, 1991; Merriam, 1998); discourse analysis (Lemke, 1990, 1998a) | Sections 3.3 and 3.4 [a] Sections 2.3.4, 3.6.2.4 and 3.6.3.2 |
| RQ2 What are the teacher's beliefs, referents, and actions in the integration and implementation of *BioLogica*? | | V | V | V (teaching scheme, time-table, handouts etc.) | T | Verbal analysis (Chi, 1997); discourse analysis; explanations (Ogborn et al., 1996) | Section 5.1, 3.6.2 and 3.6.3 |
| RQ3 What are the major barriers to using *BioLogica* activities in classroom teaching? | | V | V | | T | Verbal analysis, discourse analysis | Sections 3.6.2 and 3.6.3 |
| RQ4 What are the factors from the social/affective perspective that influence students' interaction with *BioLogica* in their conceptual learning of genetics? | V | V | V | | S | Verbal analysis | Sections 3.6.2, 3.6.3, 3.7.2 |
| RQ5 Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? If so, to what extent and in which types of genetics reasoning? | N | V | | N, V (test marks/ test scripts, log files) | S | Interpretive framework, verbal analysis | Sections 3.6.1, 3.6.2, 3.6.3, 3.7.2 |
| RQ6 What are the students' gene conceptions before and after the lessons that include *BioLogica*? | V | V | | N, V (test marks/ test scripts, log files) | S | Interpretive framework, verbal analysis | Sections 3.6.2, 3.6.3, 3.7.2 |

[a] Sections 3.3 (interpretive research methodology, Gallagher, 1991) and 3.4 (case study methodology, Merriam, 1998) applied to the analysis and interpretation of data in response to all research questions.

### 3.7.2 Narrative Vignettes and Stories

In this research, I used narratives or vignettes to portray some instances of social action in events that took place between students or between students and the teacher in the classroom or computer room. In doing so, I am using an approach which is case-oriented rather than variable-oriented according to Miles and Huberman (1994). For example, I used vignettes about Miss Bell's unique teaching experiences in School B (see Chapter 5) and vignettes about special episodes of classroom interactions in other results chapters. A vignette is an analytic narrative for reporting fieldwork. According to Erickson (1986), a vignette is:

> a vivid portrayal of the conduct of an event of every day life, in which the sights and sounds of what was being said and done are described in the natural sequence of their occurrence in real time. The moment-to-moment style of description in a narrative vignette gives the reader a sense of being there in the scene. (pp. 149-150)

There has been an increasingly popular trend in using narratives, case studies or vignettes in reporting about teaching and teacher education in Australia (see for example, Loughran, Mitchell, Neale, & Toussant, 2001; Wallace & Louden, 2000). I will discuss the limitations of using narratives in reporting case studies in the results and discussion chapters.

### 3.7.3 From Within-case to Cross-case Analyses

As explained in the preceding sections, a multiple-case design imposes high demand for time and energy but allows cross-case analyses leading to generalisations about the case. In the context of this study, the generalisations were related to what and how teachers taught and how students learnt genetics with multiple representation and some possible causal relations.

As such, cross-case analyses (see Chapters 8), as Merriam put it, seek "to build abstraction across the cases" (p. 195), that is, across four schools with six classes taught by five teachers. Given that the four schools had quite different contents and contexts in their biology/genetics lessons, it would be a daunting task of using cross-case analyses to "build a general explanation that fits each of the individual cases, even though the cases will vary in their details. The objective is analogous to multiple experiments" (p. 112). However, the logic of using multiple cases is different from that of multiple experiments in a quantitative research. Based on the theoretical framework of Yin's multiple-case design, the use of multiple cases in this research is not a *literal replication* to predict similar results but rather a *theoretical replication* in which the four case studies were expected to produce contrasting results but for predictable reasons grounded on the different contents and contexts in each case school. Yin pointed out that this replication logic "must be distinguished from the sampling logic commonly used in surveys" (p. 113). Surveys use the sampling logic to generalise the findings of a small but representative sample of a population to entire population. As I will discuss in the next section, this study followed the qualitative tradition that *generalisability* used in quantitative research is replaced by *transferability* (from one case to another of similar context) (Guba & Lincoln, 1989).

Putting cross-case analysis theory into practice, I attempted to use Miles and Huberman's (1994) suggestions, taking into account that:

> cross-case analysis is tricky. Simply summarising superficially across some themes or main variables by itself tells us little. We have to look carefully at the complex configuration of process within each case, understand the local dynamics, before we can begin to see patterning of variables that transcends particular cases. (pp. 1205-1206)

For example, in the cross-case analyses (see Chapters 8 and 9), I tried to move from the case-level causal analyses to a synthesis of a cross-case causal network. In doing so, I moved back and forth between the Miles and Huberman's *case-oriented approach* and *variable-oriented approach*. Cross-case causal networking is "comparative analysis of all cases in a sample, using variables estimated to be the most influential in accounting for the outcome or criterion" (p. 228). To make sure the interpretation is likely to be plausible, a "causal network narrative" (p. 230) was also used to provide the context, show the temporal and causal relationships and explain the chain of variables in the network (see Chapter 9).

### 3.7.4 Generating Meaning, Confirming Findings and Drawing Conclusions

Miles and Huberman (1994) suggested some useful methods of displaying data for drawing conclusion such as matrices, charts, graphs and networks. We need to move back and forth between a case-oriented approach to a variable-oriented approach in drawing the final conclusions.

Both from within the cases and across the cases, I used some of Miles and Huberman's (1994) tactics to generate meaning from the analyses: *noting patterns, themes; seeing plausibility; clustering; making metaphors; counting; making contrasts and comparisons; subsuming particulars into the general; factoring* (reducing data and finding patterns), *noting relations between variables;* and *finding intervening variables.* With the above tactics, the final steps are to *build a logical chain of evidence* and to *make conceptual/theoretical coherence*. In Chapter 9, I also used some of the Miles and Huberman's tactics to confirm the findings by verifying the conclusions—*checking for representativeness, checking for researcher effects, triangulating, weighting up evidence, using extreme cases, following surprises, looking for negative evidence, making if-then-tests, checking out rival explanations* and *getting feedback from informants* (i.e., member checks according to Guba & Lincoln, 1989). At the same time, I presented the preliminary findings of each case study in conferences and wrote some manuscripts for publication. The feedback from the conference audience and manuscript reviewers was useful for drawing and confirming the conclusions for each case study and the study as a whole. The overall picture of data collection, analyses and interpretations is summarised in Figure 3.1.

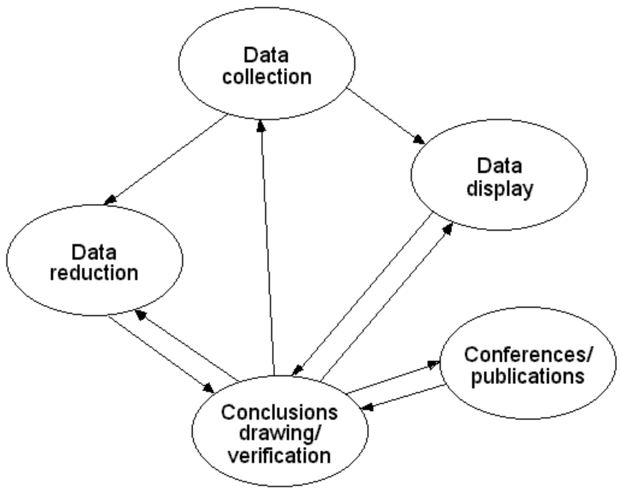



*Figure 3.1* Simplified interactive model of data analysis in this study (adapted from Miles & Huberman, 1994).

## 3.8 Validity, Reliability and Objectivity

In line with the qualitative research approach based upon a different worldview beyond the traditional positivistic paradigm, I followed the suggestion of Guba and Lincoln (1989) that *credibility/transferability*, *dependability* and *confirmability* be respectively used in place of *internal/external validity*, *reliability* and *objectivity* in experimental research.

As for *credibility*, I used some of Guba and Lincoln's (1989) techniques to establish the match between the participants' constructed realities and the researcher's reconstructions attributed to them—*prolonged engagement*, *persistent observation*, *peer debriefing*, *negative case analysis*, *progressive subjectivity*, and *member checks*. The results chapters will discuss how each of these techniques was used in each case study to increase the rigour of this research. As discussed earlier in this chapter, a multiple-case embedded design might make interpretation more compelling and would enhance the external validity (generalisability) or transferability of the findings of this case-based study.

Analysis (both quantitative and qualitative) and interpretation of data generated explanations leading to formulation of assertions that were confirmed or disconfirmed through *triangulation*. Triangulation is a metaphor derived from celestial navigation in which an navigator at sea inferred the location partly by measuring the angle of elevation of the stars at night (Stake, 1995). Three types of triangulation used in this research were *methodological triangulation*, *data triangulation*, and *theoretical triangulation* (Denzin & Lincoln, 1994; Erickson, 1986, 1998; Fraser & Tobin, 1991; Gallagher, 1991).

To illustrate triangulation used in this study, let me use the research methods in response to initial research question 4 as an example (see Table 3.3, the fourth row). In analysing and interpreting students' conceptual learning along social/affective dimension, I adopted methodological triangulation when I used interviewing, observing and online testing to collect data. In response to research question 5, I also had data triangulation when I compared and contrasted the results of the analysis and interpretation of data about student reasoning in different formats—numerical data in online tests and verbal data from the discourse in interview reasoning tasks and visual-graphical data from students' drawings and Punnett squares. As for theoretical triangulation, I analysed and interpreted student learning using several perspectives—conceptual change/science education perspective to determine status of conceptions, psychological perspective to look at student motivation, and cognitive/computational perspective to examine the roles of multiple representations in supporting learning. These strategies address some of the issues of limitations mentioned in other parts of this chapter. Although a fourth type of triangulation—investigator triangulation (Denzin, 1989)—was not possible for this study, it would be useful in using an independent investigator to establish validity through "pooled judgement" (Foreman cited in Merriam, 1998, p. 204). Mathison (1988) suggested shifting the notion of triangulation from establishing validity to constructing plausible explanations about the phenomena being studied. Accordingly, the expectation for simple convergence in triangulation is unrealistic; rather, the value of triangulation is to provide "evidence—whether convergent, inconsistent, or contradictory—such that the researcher can construct good explanations of the social phenomena from which they arise" (p. 15). These issues will be discussed again in Chapter 9 when reporting the findings of this research.

## 3.9 Ethical Issues

This doctoral study followed the research ethics guidelines of the Australian Association for Research in Education (AARE, 1993)

In each case school, before the research started, I first explained to the participating teacher(s) clearly about what would be done in data collection, analysis and reporting (see a sample letter in Appendix 3, Document A3.2). Through the teachers' introduction and support, I talked to the students about the research and invited them to participate. Informed consent was obtained from all participants. For minors, signed permission from their parent or guardian was obtained. Pseudonyms were used for all participants to maintain anonymity and confidentiality. Participants had the right to withdraw from the project at any time they wished without the need for an explanation and that all data collected would be kept confidential and anonymous. Participants could view and amend their own data. No names of the schools, nor their information that would help their identification, were and would be used in this thesis or in conference presentations, and publications.

These measures taken to preserve the confidentiality and anonymity of participants are important to the rigour of the study. Not only did such measures protect the rights of the participants but they also ensured that the participants had some kind of rapport and trust in me and were more willing to provide me with information during data collection.

As discussed in section 3.6.3, my persistent observations in the classroom were inevitably associated with the ethical issues and the tensions of intrusion into and interruption of the normal classroom life of the teacher and the students. During my classroom observations in all the case studies, I was very careful to minimise my intrusion and interruption but my presence in the classroom was always felt by everyone. On some occasions, however, I requested the teacher to give some instructions on how to use the *BioLogica* program or a teacher asked me to explain to students about it. In School D, I was invited by Ms Elliott to have some co-teaching with her to give students feedback on the online tests and their *BioLogica* activities log files. In this way, my role became more like a participant than an observer and the intrusion became collaboration with the teacher to help student learning.

## 3.10 Limitations of Methodology and Methods

Like any other research methodologies, the case study methodology has its limitations. According to Merriam's (1998) review of the literature, the following aspects about case studies can be critiqued: (1) case studies are too costly in terms of time or funds to produce rich and thick description; (2) oversimplification or exaggeration of the situation in case study reports can lead to erroneous conclusions about the reality; (3) there may be an over-reliance on the data collection and analysis process by the case study researcher who may not have had enough training; (4) an unethical case writer may select among available data for his or her wishful illustration; (5) a case study may be faulty due to its lack of representativeness, and (6) there may be a lack rigour due to the bias or subjectivity of the researcher or others involved in the case study. Most of these limitations may be applicable to this research. I will revisit some of these limitations again when discussing the findings of this research in the results chapters and in Chapter 9.

The four case schools in this study were different in contents and contexts and in Year levels so that the data could not be pooled across the cases. However, the data from different sources across the cases may be compared and contrasted for understanding the issues arising from the research questions. The use of multiple-case design was justified in this study by what Merriam (1998) said, "[t]he more cases included in a study, and the greater the variation across the cases, the more compelling an interpretation is likely to be" (p. 40). But for a multiple-case study, there are also disadvantages which require extensive resources and time beyond the means of a single researcher. An embedded design may focus only on the subunit level and fail to return to the larger unit of analysis (Yin, 1994). The next chapter will report the results of the first case study in School A.

# Chapter 4

# Case Study One:

# Teaching and Learning Genetics

# with Multiple Representations as a Supplement

## 4.0 Overview

The case study in School A was originally conceptualised as a pilot study in this research. The study, which started in April 2001, involved a very experienced science teacher, Mr Anderson (pseudonym) and his Year 10 class. Despite some initial technical problems, more data were collected and I was able to stay in the school for a longer time than expected. I decided early on not to consider this study as a pilot study. This is in keeping with a qualitative study being "emergent and flexible, responsive to changing conditions of the study in progress"(Merriam, 1998, p. 8). The study at School A then became Case Study One to be followed by the case studies in Schools B, C and D, each of which was unique in both its content and context.

Case Study One provided me with the initial experience of working in a school where a participating teacher taught genetics with *BioLogica* in a Year 10 class. Notwithstanding Mr Anderson's very busy school life, he had given me useful comments and suggestions during the study. As for the participating students, they were generally interested in using *BioLogica* and although after instruction they improved their genetics reasoning, their gene conceptions were not sophisticated (Venville & Treagust, 1998). The online tests and interviews allowed me to probe their understanding and elicit their perceptions of the learning experiences. The rich corpus of data from multiple sources had allowed me to make a good start and informed the next stage of my research. As I proceeded to work in School B (June-July 2001) (see Chapter 5), I became more focused on some issues identified in this case study.

## 4.1 Methods

Case Study One is one of the four case studies in this research using an interpretive, multiple-case embedded design (Erickson, 1998; Gallagher, 1991; Merriam, 1998; Yin, 1994) as explained in detail in Chapter 3. Within the methodological framework of this research, I will describe, in the following sections, the case specific methods in data collection, analysis and interpretation.

### 4.1.1 Specific Research Questions

As the research progressed, the study became focused on both the computer-based multiple external representations (MERs) and the teacher's different representations of genetics. When I started to collect, analyse and interpret data from School A, I continuously reviewed the literature and had more conversations with my peers and experts. I came to identify some emergent issues and pose some new questions. For instance, further questions arose about what I should follow up in the second teacher and student interviews to explore the issues further. As such, seven specific research questions were reformulated from the six generic research questions (see Chapter 3) as follows as RQ4.1 to RQ4.7:

RQ4.1 How does Mr Anderson integrate and implement *BioLogica* in his classroom teaching and learning of genetics?

RQ4.2 What are Mr Anderson's beliefs, referents, and actions in the integration and implementation of *BioLogica*?

RQ4.3 What are the major barriers to using *BioLogica* in Mr Anderson's classroom?

RQ4.4 What are the factors from the social/affective dimension that influence students' interactions with the computer-based multiple external representations in *BioLogica*?

RQ4.5 Do students improve their genetics reasoning before and after the lessons that included *BioLogica*? (Do they exhibit conceptual change from an epistemological perspective?)

RQ4.6 What are the students' gene conceptions before and after the lessons that included *BioLogica?* (Do they exhibit conceptual change from an ontological perspective?)

RQ4.7 Is there any relationship between the students' conceptions of genetics and their genetics reasoning?

In these research questions, *BioLogica* is used to mean both the multiple external representations of genetics and the technological tools for learning. As in other results Chapters 5, 6 and 7, the findings of Case Study One will be presented in terms of assertions after the data analyses and interpretations in each section.

Table 4.1, which is similar to Table 3.3, maps the methods of this case study to the case specific research questions. Data from each of the multiple sources were collected in response to one or more of these research questions as will be described and explained in the subsequent sections.

### 4.1.2 School Context

The case study was conducted in a state co-educational senior high school for Year 8 to 12 students in the Perth metropolitan area of Western Australia. Mr Anderson, who had 27 years of teaching experience when the research was conducted, included three *BioLogica* activities in his teaching of genetics in his Year 10 class during the unit *Biological Change*[16]. Student participation in the research was voluntary. Subsequently, 24 or 73% of the 33 students in Mr Anderson's class participated in the study and seven students, including four target students, were interviewed once or twice. All 24 participating students (13 boys and 11 girls) have English as their first language and their age was either 14 or 15 years when the research was conducted.

[16] A unit in the Unit Curriculum, a state-wide science education curriculum for Years 8-10 in Western Australia (Education Department of Western Australia, 1987).

Table 4.1

*Mapping the Research Methods to Research Questions in Case Study One*

| Research Question | Data Collection Method (V = verbal data; N = numerical data) | | | | Source (T= teacher; S=students) |
|---|---|---|---|---|---|
| | Online tests | Interviews | Observations | Documents | |
| RQ4.1How does Mr Anderson integrate and implement *BioLogica* in his classroom teaching of genetics? | | V | V | V (teaching scheme, time-table, handouts etc.) | T |
| RQ4.2 What are Mr Anderson's beliefs, referents, and actions in the integration and implementation of *BioLogica*? | | V | V | | T |
| RQ4.3 What are the major barriers to using *BioLogica* in Mr Anderson's classroom? | | V | V | | T |
| RQ4.4 What are the factors from the social/affective perspective that influence students' interaction with the computer-based MERs in *BioLogica* | V | V | V | | S, T |
| RQ4.5 Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? (Do they exhibit conceptual change from an epistemological perspective?) | N, V | V | | N, V (test marks, assignment/ test scripts, log files) | S |
| RQ4.6 What are the students' gene conceptions before and after the lessons that include *BioLogica*? (Do they exhibit conceptual change from an ontological perspective?) | V | V | | N, V (test marks, assignment/ test scripts, log files) | S |
| RQ4.7 Is there any relation between the students' conceptions of genetics and their genetics reasoning? | N, V | V | | N, V (test marks, assignment/ test scripts, log files) | S |

### 4.1.3 Data Collection, Analysis and Interpretation

In response to my call for participants, Mr Anderson invited me to his school (School A) in Term 1 (April 2001) to demonstrate *BioLogica* to him and his colleagues. Interested in the program, he decided to participate in my project in Term 2 when he was teaching the unit Biological Change of which genetics forms the major part. As discussed in detail in Chapter 3, multiple sources of data were collected. Figure 4.1 shows the teacher's teaching and the research progress in School A. The detailed chronology of events is given in Table A1.4.1 in Appendix 1. In the following sections, I briefly describe the methods which were first tried out in this study.

#### *4.1.3.1 Semi-structured Interviews*

The preinstructional teacher interview was conducted before the teaching of genetics began but the preinstructional student interviews were conducted at the beginning of the teaching of genetics. Because I could only interview students during recess or lunch break and because some interviewees were absent from school, some preinstructional interviews were actually conducted when instruction had begun. The postinstructional interviews took place after all the teaching had been completed. Student interviews collected information about the students' gene conceptions, their genetics reasoning and their perceptions about learning, whereas the teacher interviews focused on the teacher's beliefs, expectations and perceptions about his teaching using *BioLogica*. All the interviews were transcribed verbatim and the teacher interview transcripts "member-checked" (Guba & Lincoln, 1989, p. 238) and amended by Mr Anderson to increase the validity.

#### *4.1.3.2 Online Tests*

A website called *BiologicaOz* (see Appendix 2, Figure A2.1.1), developed using *WebCT* software on the network server of the Curtin University of Technology, was used for delivering online tests and questionnaires to the participating schools. The website also allowed participating teachers to design their own virtual classroom for supporting the teaching of genetics with *BioLogica*. Mr Anderson in this study used the website for his students to do the online tests only.

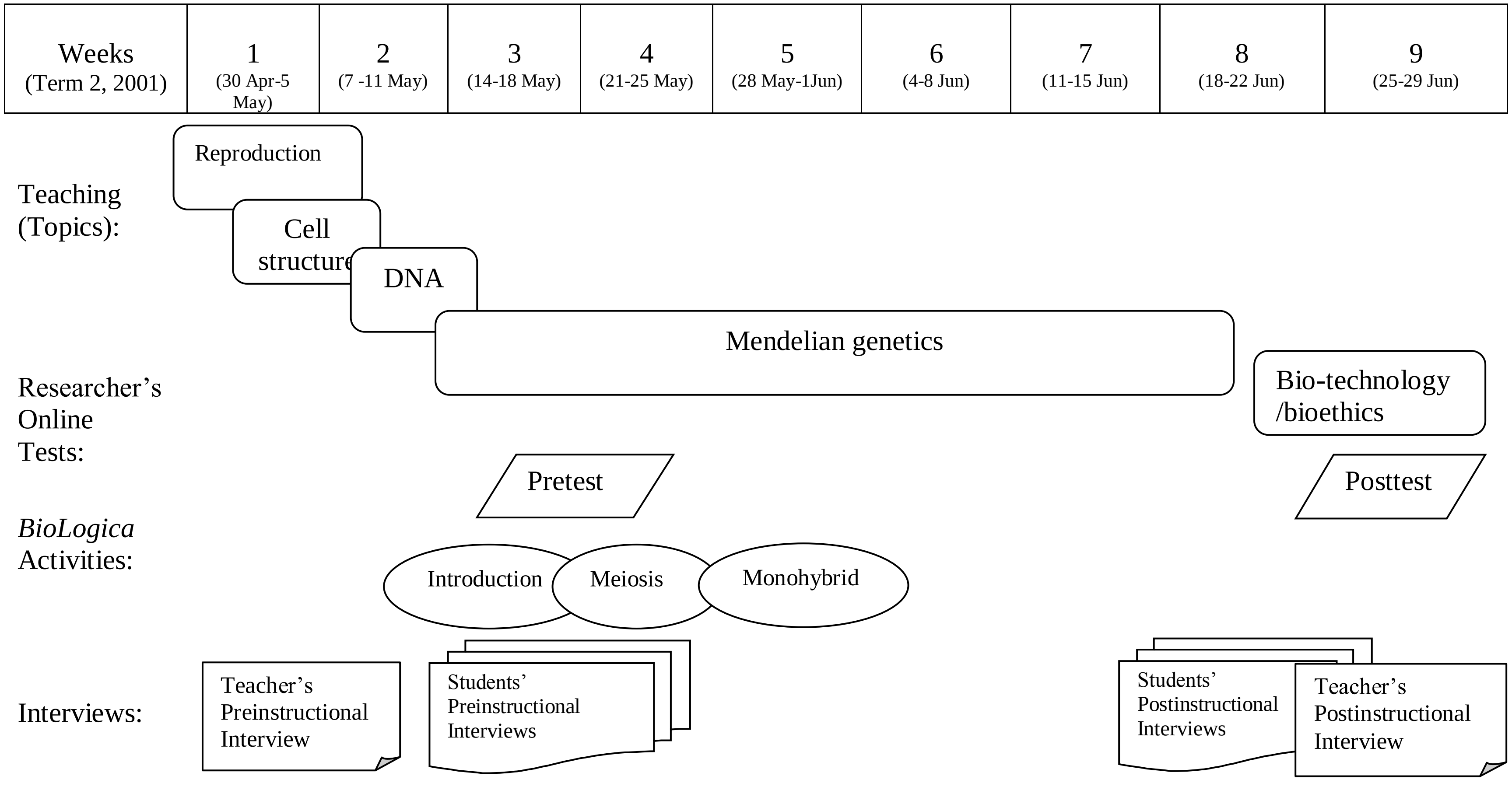



*Figure 4.1* Chronologically-ordered matrix of events of teaching and research in School A (see Appendix 1, Table A1.4.1 for details).

The online tests, like student interviews, collected these three types of information — gene conceptions, perceptions about learning and genetics reasoning. Researcher-designed two-tier multiple choice items (Treagust, 1988) gauged the students' genetics reasoning and alternative conceptions before and after the instruction. For Case Study One, the online pretest and posttest contained six two-tier parallel items on genetics reasoning and several open-ended questionnaire items that probed students' gene conceptions and elicited their perceptions of learning genetics with *BioLogica*. A sample of pretest/posttest parallel two-tier items are given in Figures A2.4.1 to A2.4.6 in Appendix 2.

#### *4.1.3.3 Classroom Observations*

I spent nine weeks in the school observing most of Mr Anderson's lessons (for a total of about 16 hours) before and when genetics was being taught (over 6 weeks), conducting the interviews and collecting other data. Four lessons were videotaped/audiotaped and were then transcribed verbatim for analysis. For every lesson observed I wrote field notes, reflective journals and expanded them as soon as possible after the observation. I also collected the log files after each of the three computer sessions but was unable to collect all because of the limited access to the computer room and other technical problems with the computers.

#### *4.1.3.4 Documents and Artefacts*

The corpus of data from school A also included the teachers' test and assignment marks and the *Student Outcome Statements* levels which the teacher had awarded to each of the participating students based on their overall work on the unit Biological Change of which genetics constituted a major part. The *Student Outcome Statements* are part of the *Outcome and Standards Framework* of the Education Department of Western Australia (Education Department of Western Australia, 1998), which enables state school teachers to understand and report on the achievements required of their students.

## 4.2 Integration of *BioLogica*: Mr Anderson's Expectations

Genetics is part of the unit *Biological Change* in Year 10 science in schools in Western Australia. With the implementation of the new Curriculum Framework (Curriculum Council, 1998) and the Student Outcomes Statements (Education Department of Western Australia, 1998), the teaching scheme about genetics (see Appendix 3, Document A3.4.1) in School A still basically followed the outline suggested by the Unit Curriculum (Education Department of Western Australia, 1987). The students were engaged in *BioLogica* activities for two and a half lessons among the 11 lessons (80 minutes each) on genetics during the six weeks of genetics teaching in Term 2 in 2001 (see Appendix 1, Table A1.4.1) and Mr Anderson referred to the program from time to time during his classroom teaching. In the preinstructional interview (8 May 2001), Mr Anderson said that he wished to use the computer program to supplement his teaching of genetics for the following four reasons. These constitute supporting evidence for generating Assertion 4.1 in response to Research Question 4.1.

### 4.2.1 To Address Student Learning Difficulties

When asked which parts of genetics was previously found to be difficult for his students, Mr Anderson mentioned about genetic crosses (or monohybrid crosses in Year 10) as he said, "The kids find some of it difficult especially when they are trying to work out crosses, um…" (Mr Anderson/Preinstructional Interview).

To address this difficulty he wished to use the *BioLogica* activities, particularly the meiosis simulation, to promote student understanding. He said, "So I try and bring in…relate it back to meiosis, with the chromosome divisions" (Mr Anderson/Preinstructional Interview). He did admit that he had no time to look at the program but he believed that students would be able to visualise meiosis and crosses at the same time so that it would make their learning easier.

### 4.2.2 To Speed up Teaching and Learning

Mr Anderson repeatedly stressed that he expected *BioLogica* would speed up teaching and learning more than would paper-and-pencil work in the classroom as he said, "They [students] can cover the work quicker."

To illustrate his point about speeding up learning he used the example of the interactive Punnett square in *BioLogica* activities to compare with pencil and paper work.

> They are doing a [monohybrid] cross; drawing up a Punnett square, going through the whole process takes them probably 10, 15 minutes to work it all out. But on the computer I would expect the sort of stuff to take a fraction of the time, so that instead of doing three or four crosses in a lesson, they can do say half a dozen…"(Mr Anderson/Preinstructional Interview)

He was quite right about the interactivity in a *BioLogica* Punnett square challenge (see Figure 4.2). As multiple sources of data indicated, not only did the interactive Punnett square speed up learning about the algorithm for predicting the phenotypic outcomes but it also might connect that learning to microscopic biological processes—meiosis and fertilisation and the symbolic pedigree—as shown in Figure 4.2.

### 4.2.3 To Motivate Learning

Mr Anderson expected that the use of the *BioLogica* Dragons[17], as novel entities vis-à-vis textbook materials, would be a motivating way of learning genetics. He said:

> [I]t's got the novelty effects of the Dragons. I won't use the pea plants and I won't use the hamster, with the stuff on humans. I'll talk about that, but I'll go from *BioLogica* to talk about the human side of genetics later. Make life easier. Yeah, so it is a motivational thing. (Mr Anderson / Preinstructional Interview)

Classroom observations indicated that Mr Anderson was proud of his teaching using rich historical contexts, stories, real-life examples of human genetics, and a personally relevant task he created each year for his class—*Moronsville* that included every student's name in the problem (See Document A3.4.2 in Appendix 3). It can be seen that Mr Anderson wished to use *BioLogica* as a supplement to motivate his students during his teaching of genetics, which was already richly contextualised.

[17] The version of *BioLogica* released in April 2001, had four species of organisms in the Practice Sessions which users can choose from—Dragon, Mendel's pea, hamster and budgie.

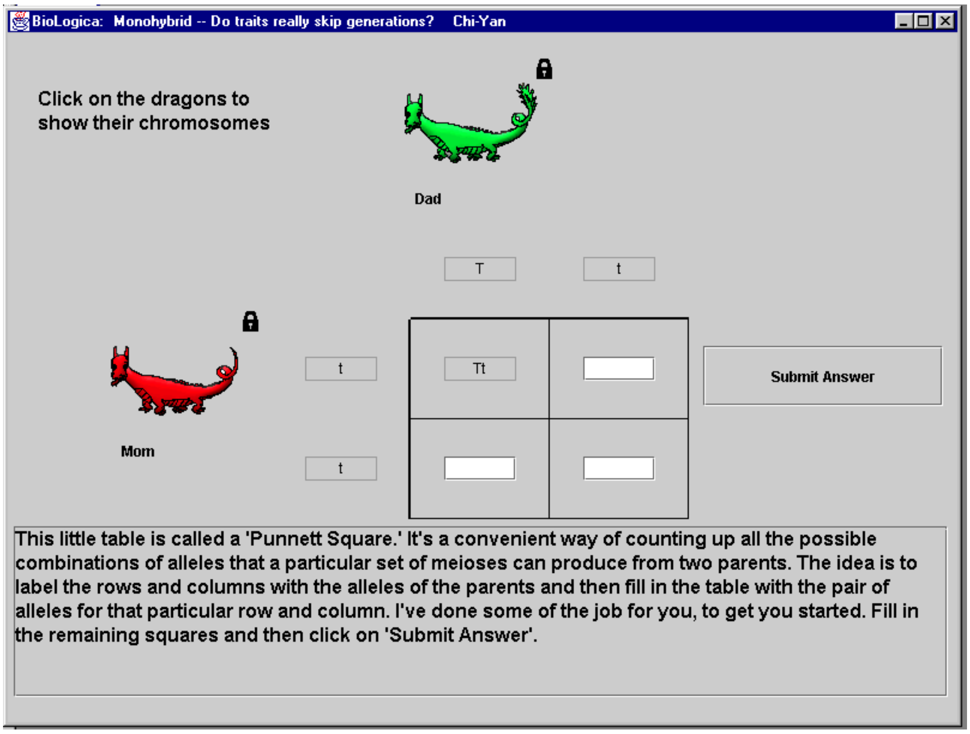



*Figure 4.2* Snapshot of *BioLogica* activity *Monohybrid* with an interactive Punnett square window dynamically linked to the Dragons' phenotype and genotype.

Another theme which Mr Anderson repeatedly mentioned in the preinstructional interview was about *BioLogica* being a *visualisation* tool:

> [T]his is when I go and use *BioLogica* again to do crosses so the kids can actually see them rather than sit there are using some textbook stuff, they can play with the Dragons…(Mr Anderson/Preinstructional Interview)

Then, he expected the visualisation effects and instant feedback provided by the *BioLogica* activities would be useful but he stressed that it was just another tool to supplement his classroom teaching.

> *BioLogica* is a good method to show them instantly what happens, so they can do the cross and see what happens they can see that their pedigree applications are good and if they are not, they can modify them. So *BioLogica* is just another tool.
>
> (Mr Anderson/Preinstructional Interview)

As we shall see in section 4.4.1.2, like their teacher Mr Anderson, the students also perceived that visualisation and *instant feedback* were useful features in the *BioLogica* program for learning genetics.

### 4.2.4 To Engender Understanding and Consolidate Concepts

While Mr Anderson emphasised that he expected *BioLogica* could speed up learning or cover more ground in learning, he also expected his students to use *BioLogica* activities to "make predictions which can then be checked very quickly", and to have experience "to test their ideas for consolidation of their concepts."

When asked about whether teachers should stress reasoning in teaching genetics, his answer was affirmative. He further said that reasoning would be useful for students outside the school as they needed "to be able to logically express themselves and think things through."

On the basis of the above four themes: to address student learning difficulties, to speed up teaching and learning, to motivate learning and to engender understanding and consolidate concepts, I generated Assertion 4.1 to address Research Question 4.1.

*Assertion 4.1*

*Mr Anderson integrated BioLogica in his classroom teaching as a supplement as he expected the program's visualisation and instant feedback to engender student motivation and understanding.*

## 4.3 Implementation of the Teaching with *BioLogica*

The following sections report on the analysis and interpretation of data leading to the generation of Assertions 4.2 and 4.3 in response to the Research Questions 4.1, 4.2 and 4.3.

### 4.3.1 Scaffolding for Students Using *BioLogica*

#### ***4.3.1.1 Pre-activity Briefing***

Mr Anderson briefed the class during each of the two computer sessions for the *BioLogica* activities *Meiosis* and *Monohybrid*. Each briefing was mainly about the procedure to start and the *BioLogica Tools* to run the program.

Mr Anderson's briefings were intended to provide a guide to the students, for starting the program and also some knowledge about the *BioLogica* Tools, such as the Magnifying Glass[18], Chromosome Tool[19], Cross Tool[20] used in manipulating the objects in the program. However, Mr Anderson might not have noticed then that in *BioLogica* there are already *pop-up* instructions and explanations for each Tool and tips with graphics and hyperlinks to a glossary of genetics terms through the Help Menu. As Mr Anderson had not spent enough time trying out *BioLogica*, he was unable to advise students to use them when they needed help. Further, he appeared to display some lack of confidence during the briefing just before the activity *Meiosis* when he said, "Um, if you have a problem you can ask me for help. I will try to help, I'm not gonna guarantee anything."

#### *4.3.1.2 Ongoing Support*

On 29 May 2001, two days before his students used the *BioLogica* activity *Monohybrid* in class, Mr Anderson asked me to work with him when he tried out this activity. On 1 June, I noticed that besides his usual briefing before the activity, he moved around and provided more active scaffolding to the students who were working with *BioLogica*. The classroom discourse was videotaped but unfortunately, the noisy environment did not allow most of the dialogues to be transcribed. One transcribed snippet (time display: 01/06/2001 12:21 pm) provides some evidence of the scaffolding which Mr Anderson provided to two students who were trying to solve a problem in the activity *Monohybrid* on the computer:

> Mr Anderson: That's your offspring. You are not looking at the chromosome and the gametes. So you need to look at the gamete chromosomes. So click that [button] there and go to the Magnifying Glass and that's the chromosome there that you are looking at. You are after tails, which is [big] T. So it is recessive. So little t is – you have to work out which one it is. You can see it has little t little t so you click on that. So you can see little t is the pointy tail [plain-tailed]. Now if you look at this one you will find that it has at least one big T in it. So, click on this and drag it across real quick. Did it work? Yeah. Good. You can see the whole process. Now this is where you do the breeding. Reset makes it go back to the original.
>
> Student: I am finished…

[18] A *BioLogica* tool to zoom a view on the screen.
[19] A tool or a cursor for clicking on the icon of an organism such as a *BioLogica* Dragon to display the its chromosomes.
[20] A tool to create baby Dragons by clicking on the male and female parent Dragons.

| | |
|---|---|
| Mr Anderson: | You can try the horns of dilemma [the activity *Horn Dilemma*]. You have to solve a problem and answer a question. I think you are given credits for it. Are you happy with what you have done with the monohybrid cross? |
| Student: | Yes. |
| Mr Anderson: | Yeah, it's not hard. Try the horns of dilemma activity. |

(Mr Anderson/Lesson/01 June 2001)

If the above transcription were complete, the dialogue would be rather teacher-dominated but it indicates here that Mr Anderson did provide some scaffolding to the students who were struggling to use *BioLogica* in several ways. First, he showed the two students, by talking and gesturing, how to use the Tools, namely, Magnifying Glass and Crossing Tool; he even told them "to drag" the Crossing Tool "real quick". Second, he used the concept words or constructed of entities (Ogborn et al., 1996) to explain genetics to the students to foster student understanding across Johnstone's (1991) three levels: *chromosome* in the *gametes* (microscopic level), "little t little t" or genotype (symbolic levels) is the "pointy tail" or the *phenotype* (macroscopic level). Third, he checked students' progress, gave them encouragement and guided them to the next activity.

#### *4.3.1.3 "Jot down something. Don't just keep going."*

Mr Anderson repeatedly asked students to make some notes if they did not understand, for example, he said in his briefing before students started the activity *Meiosis* in the computer room:

> [A]dd to your notes when you feel the need. Now I've added that there because you may get into it and suddenly think 'Ooh! something's clicked; this is happening, I think. Jot something down. Don't just keep going. Okay. So when you get something you think could be relevant, jot it down. If you're not sure, put a question mark next to it or something like that. (Anderson/Lesson/21 May 2001)

Before the *Monohybrid Activity* on 1 June 2001, Mr Anderson reiterated the same reminder in his briefing of the class. He said, "You will need a piece of paper. It can be a piece of scrap paper and I want you to write down what's going on as you go through. So you are actually thinking and predicting." And then later he said, "The important thing is that you write down your reasons, your answers and the whys, so you understand what's going on. That's the key – not to have lots of fun".

(Mr Anderson/Lesson/1 June 2001). However, according to my observation in both computer sessions, only about half of the students followed Mr Anderson instructions to make notes.

### 4.3.2 Linking Classroom Teaching to Student *BioLogica* Experiences

Observational data indicated that Mr Anderson linked his classroom teaching several times to students' previous experiences in using the *BioLogica* activities. On 28 May 2001, a week after students had the *BioLogica* activity *Meiosis,* Mr Anderson taught about meiosis in the classroom. About 1 minute into the lesson, he said:

> So genotype is what genes you've got for a characteristic. You may express, or show, one gene. Remember in the Dragons; they show a characteristic [but] what you see, doesn't necessarily reflect, the genes you've got only. (Mr Anderson/lesson/video transcript/28 May 2001)

And then after about 5 minutes, he again evoke the images of the *BioLogica* activity *Meiosis* by saying:

> Now, if you remember, Monday, when you did the meiosis um, computer simulations, you notice you start off with one cell, and it divides in half, and then divides in half again. You end up with four cells. We're gonna go through a little more detail in that in a minute. (Mr Anderson/lesson/video transcript/28 May 2001)

Similarly on 31 May 2001, on day before the students would work on the next *BioLogica* activity *Monohybrid*, Mr Anderson taught about the symbols used in constructing pedigrees (family trees) in monohybrid crosses and he tried to conjure up the images of the Dragons which his students would use on the following day using this as an advance organiser (Ausubel, 1968). He said:

> I just brought this [how to draw a family tree] in because when you go to the computer room to play with the Dragons, and breed your Dragons tomorrow, you're going to draw up family trees and if you don't know what some of the symbols mean and that you could spend ages just trying to sort out what this new thing is, and miss the point of the whole exercise. Okay? (Mr Anderson/lesson/video transcript/28 May 2001)

As can be seen from the preceding lesson transcripts, Mr Anderson tried to conceptually link his normal classroom teaching about *genotype-phenotype relationship*, *meiosis process* and the *pedigree chart* to the *BioLogica* activities which their students had done or would do. This normal classroom teaching augmented the contribution of the *BioLogica* experience to students understanding. Indeed, as will be discussed in Chapter 8, cross-case analyses indicated that School A students fared slightly better than the students in School C, a laptop school, in terms of their preinstructional-postinstructional improvement in genetics reasoning. Assertion 4.2 was generated in response to Research Questions 4.1 and 4.2.

*Assertion 4.2*

*Mr Anderson implemented BioLogica to provide students with drill and practice for what he had taught in class; his beliefs and referents for his action might be related to Piagetian ideas.*

### 4.3.3 Barriers to Using *BioLogica* in Teaching and Learning

#### ***4.3.3.1 Time Constraints and Knowledge about the Software***

Perhaps the time constraints of his normal school activities prevented Mr Anderson from making better use of *BioLogica* in his teaching. In the preinstructional interview, he said "But that's really all because I haven't seen the program yet, I haven't had time" and "because we are a bit short on time". As such, it was not easy to fit the three computer sessions into his rather tight teaching schedule. From my observations, he had not had enough time to try out the program beforehand and to know more about the three *BioLogica* activities, *Introduction*, *Meiosis* and *Monohybrid,* which he would use in teaching. However, he did try to tie the *BioLogica* activities to what he was teaching. During the computer sessions, I observed the students using *BioLogica* to supplement their learning and finding the Dragons to be a new way of learning genetics (see section 4.4.1). Given that Mr Anderson was not too familiar with the software, what he sometimes taught was probably a repetition of what was already learnt by students in *BioLogica* or what the students would investigate in *BioLogica*.

#### *4.3.3.2 Technical issues*

Several sources of data indicate that the major cause for the technical issues was the lack of an IT person to support the teacher in using the learning technologies. Mr Anderson said:

> If you want an IT person in the school you are looking at thousands [of dollars]. To maintain that room over there and the portable laptops you are looking at another 10 grand for the computers, loading them you are looking at too much money and there is no money in the government system. (Mr Anderson/Postinstructional Interview)

As the school could not afford a full-time IT person, Mr Anderson himself initially tried for hours to install the program in the school network without success. He became very frustrated according to his email messages to me and then he had to ask an IT person, paid hourly by the school, to help install the software. Not only did the technical issue frustrate Mr Anderson when he attempted to install the program but it also impeded the full potential of *BioLogica* being used by the students during the three *BioLogica* sessions in the computer room. What I noticed, as a participant-observer, was that some machines did not work well. When students sometimes had problem in running a *BioLogica* activity, they had to share a computer with other classmates.

From my experiences working with teachers in several other schools I had visited, *BioLogica* appeared to be very easy to install when an IT person was there to help. As I found out later, the installation of *BioLogica* and its use was never a problem in all the other three case schools. However, the findings in School A alerted me about the technical issues, which I needed to carefully, consider at the planning stage for other case schools.

In summarising the finding in this section guided by Research Question 4.3, I have the following assertion:

*Assertion 4.3*

*The major barriers in using BioLogica in Mr Anderson' classroom were the time constraints, knowledge about the program, and technical issues.*

## 4.4 Conceptual Learning Outcomes

### 4.4.1 Motivational Outcomes: Conceptual Learning along the Social/affective Dimension

This section first examines students' *personal interests* and how they responded to the *situational interests* they identified in the MERs of *BioLogica*. Then, the section explores *intrinsic motivations*—the most significant finding about the social/affective dimension of conceptual learning in this study (see the literature review in Chapter 2 sections 2.2.8.2 and 2.2.8.3). Two assertions will be generated at the end of this section in response to Research Questions 4.4.

#### *4.4.1.1 Student Personal Interests in Learning Genetics*

Data from multiple sources indicated that students' personal interest was important to engage them in the computer activities for learning genetics. *BioLogica* appeared to be motivating for most students but not for several students who said they did not like genetics.

Before using *BioLogica*, 18 out of 24, i.e., 86% of the participating students, said they liked genetics as indicated by their online responses to an open-ended questionnaire item. These 18 students gave a number of different reasons for liking this topic. The major reason was an unspecified personal interest and an intention to learn more about the knowledge of genetics but only one student considered a career related to genetics (see Table 4.2).

As reviewed in Chapter 2, *intentional learning* has recently become an emergent research agenda (Bereiter & Scardamalia, 1989; Sinatra & Pintrich, 2003b). Interestingly, two students, Matthew and Doug, whose reason for their interest in genetics was *challenge,* turned out to be the only two students who scored full marks in the genetics reasoning posttest (see Appendix 1, Table A1.4.4) and they were also awarded by Mr Anderson Student Outcome Statements Level 6 (Education Department of Western Australia, 1998) which is highest level for a Year 10 class.

*Table 4.2*

*Student Interests in Learning Genetics (School A)*

| Interest in Genetics [a] | | Number of Students | |
|---|---|---|---|
| | | Pretest (*n* = 18[b]) | Posttest (*n* = 18[b]) |
| Unspecified personal interest | | 10 | 12 |
| Genetics knowledge | | 8 | 9 |
| Medical advancement | | 2 | 1 |
| Scientific career | | 1 | 1 |
| Controversial topic | | 1[c] | 1[c] |
| Challenge | | 0 | 2[d] |
| For examination | | 2 | 0 |
| Human survival | | 1 | 0 |
| Other | Because science (genetics) is cool | 1 | 0 |
| Reasons: | Because genetics is different | 1 | 0 |
| | Because it is a newly discovered topic | 1 | 0 |

[a] Students' interests were coded from their online responses to the open-ended questions: "Would you like to learn more about genetics? If yes why? If not, why not?" (Pretest) and "Did you like learning genetics in the past few weeks? If so, what did you like?" (Posttest)

[b] Only 18 respondents said "Yes" and gave one or more reasons for their interest in genetics; two said "No" in the both the pretest and posttest; three other responses were not clear. Three participating students did not do the pretest and one did not do the posttest.

[c] Same respondent.

[d] The respondents, Matthew and Doug, were the only two students who scored 100% in the posttest and they were both awarded Student Outcome Statements Level 6 (Education Department of Western Australia, 1998) by their teacher.

For the three participants who said they did not like genetics, two said that they found the subject boring. One had some personal reasons. However, their beliefs appeared to be resistant to change. Five weeks later, i.e., after instruction, two of them again said they still did not like genetics. The third did not take the posttest. In the online pretest (18 May 2001), Eleanor wrote "no...it doesn't interest me" and then she responded to a parallel form of the open-ended questionnaire item in the posttest (25 June 2001) by writing "No I don't understand it and I find it boring. I don't see how it's going to be of any use to me in later life [but] making baby Dragons was OK." Those students (*n* = 6) who had negative or mixed perceptions did not do well in either the researcher's or the teacher's tests. Nor did they complete all the teacher's assignments. *BioLogica* obviously could not motivate their learning of genetics and some of them did find genetics too difficult to understand.

#### *4.4.1.2 Salient Features of BioLogica: Situational Interests*

The rich visual-graphical representations in *BioLogica* linking concepts of genetics at different levels appeared to make learning interesting and enjoyable. In the students' perceptions in the interviews and online tests, I identified three emerging themes of *situational interest* (Pintrich, 1999) about the features in *BioLogica*: *visualisation*, *instant feedback*, and *flexibility* to be discussed in following sections.

**Visualisation**

Visualisation involves linked visual-graphical representations in *BioLogica* and may deepen students' understanding of the connection between representations and concepts (Wu et al., 2001) that require multilevel thinking (Johnstone, 1991). Visualisation particularly "make[s] meaningful connection between processes and their observation manifestations (e.g., the connection between meiosis /fertilisation and Mendelian genetics) (Kindfield, 1992, p. 39). For example, Laurie and Nelly made similar comments in their interviews about how they could learn better with visualisation (see Table 4.3).

**Flexibility**

Flexibility means that *BioLogica* controls the flow of a student's activity from changing the screen views in response to the student's actions (Horwitz & Tinker, 2001) so that students can work at their own pace.

**Instant feedback**

Instant feedback describes the way *BioLogica* immediately responds to students' actions (e.g., students' creations of organisms or their mouse clicks to select objects) by communicating with them through graphics and texts (Horwitz & Tinker, 2001). Reflecting upon their experiences of using *BioLogica*, four interviewees including Eric talked about instant feedback in their postinstructional interviews (see Table 4.3).

Mr Anderson, too, had similar ideas about this aspect of *BioLogica*. On his reflection upon the experience of teaching with *BioLogica*, he made the following comments in the second interview:

The only thing they got out of that [*BioLogica*] was doing the crosses and getting an instant feedback. They could see it and that was probably the comment they made, that they could actually see the process and the end result very quickly without having to imagine it. (Mr Anderson / Postinstructional Interview/27June2001)

These salient features constituted situational interest that made *BioLogica* intrinsically motivating to the students. As will be discussed in the following chapters, most participating teachers and students in other case studies unanimously identified these features in *BioLogica*.

Table 4.3

*Salient Features of BioLogica as Perceived by School A Students*

| Salient feature of *BioLogica* [a] | Number of Students[b] (%)($n$ = 24) | Data Source | Sample Quotes |
|---|---|---|---|
| Visualisation | 7 (29%) | I[c] and O[d] | It's good with the Dragons because with humans you don't notice much change, but with the Dragons it's a total change. So you understand eventually why they have different traits.<br>(Laurie/Preinstructional Interview/29May2001)<br>You can relate, a lot of it more, by just seeing pictures of the cell division and everything, seeing how that happened, you can imagine how things are gonna happen.<br>(Nelly/Postinstructional Interview/25June2001) |
| Flexibility | 5 (21%) | I and O | I liked learning about genetics because it is interesting. It was fun using *BioLogica*, especially because we could work at our own pace, and do as much work as we wanted to do. It was much better than being in a classroom. (Nelson/Online Posttest/25June2001) |
| Instant feedback | 4 (17%) | I only | You can see if you are right or not. Because, well, if you think what a Punnett square is, instead of writing it down, if you're crossing something over you're not sure if you're right or not. So on the computer you can actually see if you are right. (Eric/Postinstructional Interview/21June2001) |

[a] These features were mentioned in response to the interview questions/online open-ended questionnaire about their experiences using *BioLogica* and no prompts were given about these features.

[b] If the feature is identified in both interview transcripts and online postings of a student, he or she is only counted once.

[c] Interview data.

[d] Online open-ended questionnaire data.

### *4.4.1.3 Intrinsic Motivations*

Most students enjoyed manipulating the MERs in *BioLogica*, particularly the *Dragons*, as representations of genetics knowledge (Tsui & Treagust, 2003). During the preliminary analyses and interpretations, I identified in student interview transcripts and online test responses, five themes about motivation: *challenge*, *control*, *curiosity*, *control*, and *peer support*, which are similar to Malone and Lepper's (1987) intrinsic motivations (see section 2.2.8.3).

Accordingly, the first four themes: curiosity, control, fantasy, and challenge are *individual motivations* and peer support is similar to *cooperation*, an *interpersonal intrinsic motivation.* These themes are discussed below. Table 4.4 shows the class-wide data analysis of students' intrinsic motivations and a sample quote from the student interviews to support each intrinsic motivation.

**Curiosity**

Curiosity provides an optimal (moderate) level of informational complexity or discrepancy from the learner's current state of knowledge and information, e.g., variability in audio/visual effect or instructional techniques that cause surprises. It appeared that *BioLogica* Dragons provided students with visualisation tools and surprises to make learning fun while they developed their understanding.

**Control**

Control promotes feelings of self-determination and control on the part of the learner, e.g., responsive learning environments, learner's choice and power. It appeared that *BioLogica* promoted feelings of control on the part of the learner using computers instead of reading a textbook or listening to the teacher.

**Challenge**

Challenge provides continuously optimal (intermediate) level of difficulty for the learner, e.g., goals, uncertain outcomes. It appeared that *BioLogica* provided some interactive challenging problems with the Dragons. Matthew's remark in the postinstructional interview was an example of challenge (see Table 4.4).

Table 4.4

*Intrinsic Motivations in Learning with BioLogica as Perceived by School A Students*

| Intrinsic Motivation [a] | Number of Students[b] (%) ($n$ = 24) | Data Source | Sample Quotes |
|---|---|---|---|
| Curiosity | 13 (42%) | I[c] and O[d] | *BioLogica* was a good way to learn about genetics because it was different to reading it out of a book. It was on hand experience that showed you meiosis and how different genes (dominant and recessive) can determine characteristics.<br>(Ada/Online Posttest/25June2001) |
| Peer support | 6 (25%) | I only | Mark: Yeah well um.... Sometimes Nelson and myself would try and work on it together if it was a hard problem and if we couldn't work it out we would ask Mr. Anderson.<br>Nelson: I agree with Mark because you could do as much as you could do. If one of us didn't understand something then we would help each other out.<br>(Mark and Nelson/Postinstructional Interview/14June2001) |
| Challenge | 5 (21%) | I and O | Well, in one of the problems I think you had to make a certain type of Dragon with certain characteristics so you had to select certain chromosomes that [have] dominant or recessive genes on them to be used as gametes to make a new Dragon. So that was interactive there.<br>(Matthew/ Postinstructional Interview/19June2001) |
| Control | 4 (17%) | I and O | um… if you are working in class you have to stop and wait for more things to do or if you are slow you can’t keep up. But because you are doing it at your own pace you learn more and get more things done.<br>(Nelson/Postinstructional Interview/12June2001) |
| Fantasy | 3 (13%) | I only | Yeah, because it’s (a Dragon’s) made up; it’s not real; it makes it more fun; like if you had humans on the computer it's a bit boring because you see them every day. So you can do it with some animals and stuff like that, it’s more interesting.<br>(Eric/Preinstructional Interview/21May2001) |

[a] They mentioned about these themes that had motivated them in response to interview questions/ online open-ended questionnaire items about their experience using *BioLogica* and no prompts were given when students talked about these features.

[b] If the feature is identified in both interview transcripts and online postings of a student, he or she is only counted once.

[c] Interview data.

[d] Online open-ended questionnaire data.

**Fantasy**

Fantasy evokes mental images of physical or social situations not actually present, e.g., appeals to emotional needs of learners, metaphors and analogies. It appeared that *BioLogica* evoked in students mental images of situations not actually existing, in particular, the fictitious Dragons which are different from humans whom the students see every day. An example of fantasy is Eric's remark about having more fun learning with the Dragon that is "not real" (see Table 4.4).

**Peer Support**

Peer support is similar to *cooperation*, one of Malone and Lepper's (1987) interpersonal intrinsic motivations. Accordingly, *cooperation* enlists the individual motivation in cooperating with others to enhance the appeal of the activity, e.g., to solve an interesting but challenging problem together. It appeared that *BioLogica* allowed the students to learn together. The dialogue between Mark and Nelson during the interview illustrated peer support (see Table 4.4).

Based on the analysis and interpretation in section 4.4.1, *BioLogica* Dragons appeared to be intrinsically motivating for many students as is illustrated by the class-wide perceptions based on interviews and online test postings (see Table 4.4). With respect to Research Question 4.4, the finding of this section is now summarised in Assertions 4.4 and 4.5 as follows:

*Assertion 4.4*

*Many students, personally interested in genetics, found BioLogica intrinsically motivating because of the salient features of BioLogica MERs (situational interests).*

*Assertion 4.5*

*Students' motivations appeared to affect their decision to learn, their task engagement, and their interactions with the MERs.*

### 4.4.2 Students' Conceptual Learning along the Epistemological Dimension

#### *4.4.2.1 Motivation and Learning*

The analyses and interpretations of the students' online tests, computer log files, interview/lesson transcripts, and video data indicated that student engagement in *BioLogica* activities did contribute to their construction of understanding of genetics in terms of their improvement in genetics reasoning. Further, the analyses and interpretations suggested how students developed their genetics reasoning using these computer-based activities. This section leads to the generation of an assertion in response to Research Questions 4.4 and 4.5.

As reported in section 4.4.1, the MERs in *BioLogica* activities intrinsically motivated student learning because of the situational interests of three salient features of MERs in *BioLogica* and their personal interests. I argue here that as many students were intrinsically motivated in their learning of genetics, these students were likely to be more engaged in reasoning and problem-solving tasks than in an otherwise normal classroom situation without these computer-based multiple representations. However, three students disliked genetics (see Table 4.2, note b) and *BioLogica* activities did not motivate them in their learning. Eleanor was an example who did not like learning genetics or the *BioLogica* program.

The analysis of the log files on the *BioLogica* activity *Monohybrid* (see Table A1.4.2 in Appendix 1) provides more confirming evidence for Assertion 4.6 which follows this section. The number of attempts used to complete a challenge might indicate the user's genetics reasoning. I believe that the six challenges in *Monohybrid* activity well illustrate the second and third functions of MERs, namely, to constrain interpretation, and to construct deeper understanding (Ainsworth, 1999). These challenges, similar to White and Gunstone's (1992) *predict-observe-explain (POE)* tasks, involve predicting genotype-phenotype outcomes of a monohybrid cross between two Dragons in a pedigree (see Figure 4.2). In terms of students' perceived salient features, it can be interpreted that the MERs in *BioLogica* provided entities of genetics (objects or processes) with linked information (between an interactive Punnett square, the Dragons' phenotypes and their chromosomes with embedded genes) and the Tools (e.g., Chromosome Tool to show the Dragon's chromosomes) for visualising these entities, as well as instant feedback (*BioLogica* provides immediate feedback to users' actions, selections, and entries in a Punnett square), and flexibility in the flow of the activities (*BioLogica* is sensitive to the user's choice and allows navigation to other views). As *BioLogica* "controls the flow of a student's activity by shifting from one set of views to another in response to a student's actions"(Horwitz & Tinker, 2001, p. 3), the MERs thus constrain students' interpretation (Ainsworth, 1999) of the given information so that they take the required action in order to proceed further to complete a task or challenge. To present the findings in this section in response to Research Question 4.4 and 4.5, I generated Assertion 4.6 as follows:

*Assertion 4.6*

*Some students were able to improve their genetics reasoning because of the role of multiple external representations (MERs) of BioLogica in constraining their interpretation of the phenomena of genetics.*

Assertion 4.6 was generated as a result of Assertion 4.5 because only when the students were motivated did they engage in useful interaction with the MERs of *BioLogica* for developing their reasoning. However, log files analysis (see Table A1.4.2) and classroom observations indicated that two students, Laurie and Nelly did not improve their genetics reasoning (see Table A1.4.3) despite their high level of engagement in the activities. A new theme has thus emerged from this finding. For students to benefit from the interactions with the MERs, they need to be engaged in mindful learning (Salomon & Globerson, 1987). For instance, a student was not a mindful learner when he or she did not view the Dragon's chromosomes (genotype) while breeding baby Dragons of a required phenotype. Similarly, a student who had very *low index of interaction* (time per mouse click or other selections)[21] was not a mindful learner either.

*Mindfulness* is "volitional, metacognitively guided employment of non-automatic, usually effort demanding processes" (Salomon & Globerson, 1987, p. 623). In considering computers as *mindtools*, Jonassen (2000) argued that

[21] Buckley (Personal communication, November 8, 2001) e-mailed me in response to my earlier question that "the index of interaction isn't simply an issue of 'brightness', but also an issue of how easily they [the students] read and how much they knew before they used *BioLogica*. The index of interaction varies among [the *BioLogica*] activities."

mindfulness is required for meaningful learning, which, he defined as “learning that is applicable to similar situations and transferable to dissimilar situations.”(p. 273) and that mindfulness depends on students’ willingness and interest in learning. Given that not all the students’ log files were available in this case study, there was not enough evidence to generate an assertion regarding the role of mindfulness in connection with Research Questions 4.4, 4.5 and 4.6. As will be discussed again in Chapter 7 about Case Study Four, mindfulness is a plausible explanation for students with low prior knowledge, such as Kath and John, being unable to improve their genetics reasoning despite their high level engagement in the *BioLogica* activities.

#### *4.4.2.2 Patterns of Students’ Genetics Reasoning*

Over the period of six weeks, students used three *BioLogica* activities, *Introduction*, *Meiosis*, and *Monohybrid*. These activities feature MERs across three levels of description: Organism Level (Phenotype view), Cell Level (Cell View) and Chromosome Level (Gene/Allele View) (see section 2.3.3.4). The tasks and challenges focus on genotype-phenotype relation (cause-to-effect and effect-to-cause reasoning within and across generations or Types I to IV), and the process reasoning (across generations or Type VI) (Hickey & Kindfield, 1999) (see Table 3.1). A class-wide pretest-posttest comparison of students’ genetics reasoning across four types of genetics reasoning is graphically displayed in Figure 4.3. Some patterns were identified.

The low class mean score (25.6%) ($n$ = 21) of all pretest two-tier items on genetics reasoning—both parallel and nonparallel items—indicated that the students had limited prior knowledge when they started to learn genetics in Year 10. For most students, learning to reason in genetics was therefore rather difficult when they were unable to link the new learning to their current but limited prior knowledge. Pretest-posttest comparison of the students’ ($n$ = 20) scores on the six parallel two-tier items on genetics reasoning revealed that the posttest mean score (58.3%) was much higher than the pretest mean score (14.2%). This gain suggested that all of these 20 students except one (see Appendix 1, Table A1.4.3) had improved their reasoning over the six weeks of instruction by building upon their limited prior knowledge of genetics. When the items were further broken down into four genetics reasoning types (Hickey & Kindfield, 1999), an interesting pattern was identified (see Figure 4.3). The students' improvement in genetics reasoning was much greater in the *simple/novice types* (Types I and III) than in the *complex/expert types* (Types IV and VI) (see Table 3.1).

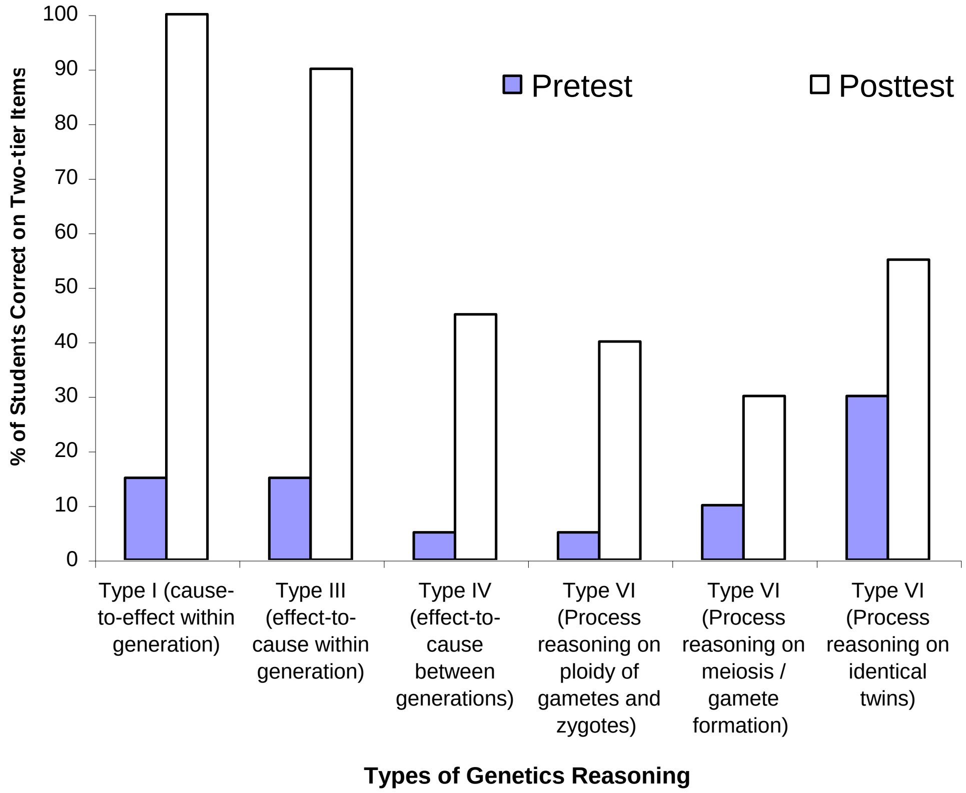



*Figure 4.3* Class-wide pretest-posttest comparison of students' genetics reasoning (*n* = 20). (All three process reasoning items (Type VI) are between generations.)

Guided by Research Question 4.5 about genetics reasoning or conceptual learning along the epistemological dimension, I generated Assertion 4.7.

*Assertion 4.7*

*Students' improvement in their genetics reasoning was only for the easier types even though they were actively engaged in BioLogica activities.*

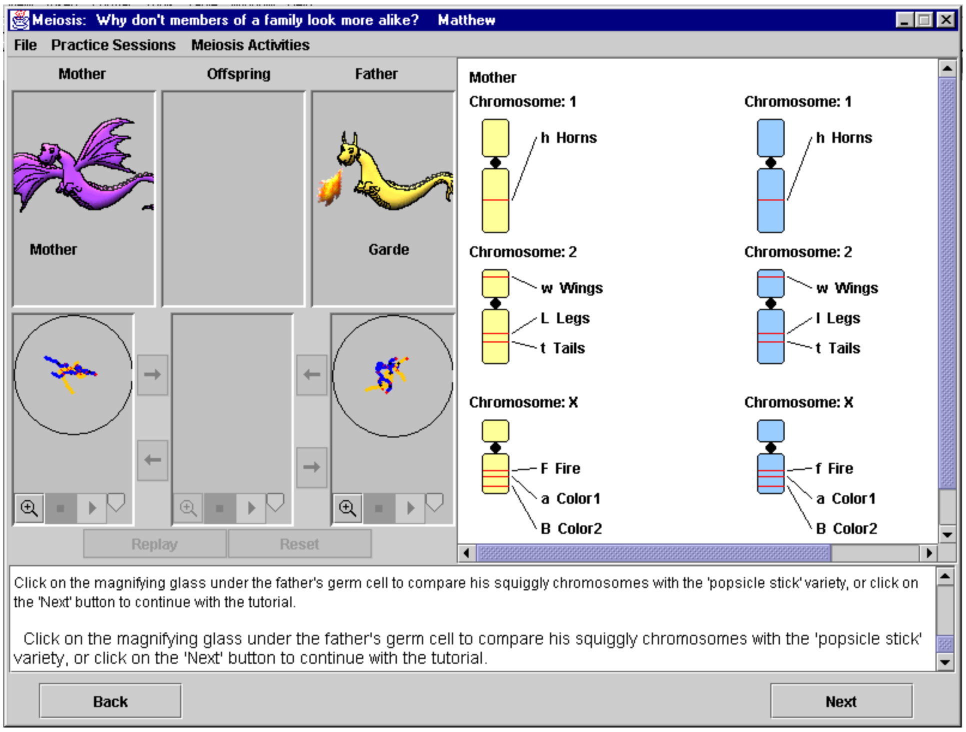



*Figure 4.4* Snapshot of the *BioLogica* activity *Meiosis* showing multiple representations of genetics.

### 4.4.3 Conceptual Learning along the Ontological Dimension

This section examines students' gene conceptions in response to Research Question 4.6. First, I will analyse and interpret the preinstructional-postinstructional change in students' class-wide gene conceptions. Then, I will focus the analysis and interpretation of the progression of students' gene conceptions in the interviewees using Venville and Treagust's (1998) framework. The findings are presented in terms of two more assertions (Assertions 4.8 and 4.9) at the end of section 4.4.3.

#### *4.4.3.1 Class-wide Gene Conceptions*

Students' class-wide preinstructional and postinstructional gene conceptions were based on their online responses to two parallel open-ended questionnaire items: "What do you know about a gene?" (pretest), and "After you have studied genetics for some weeks, what do you know about a gene now? "(posttest). The students' responses were categorised as shown in Table 4.5.

*Table 4.5*

*Pretest-posttest Comparison of School A Students' Gene Conceptions*

| Category | Gene Conception in Response to "What do you know about a gene?" | Number of Students ( %)[a] | |
|---|---|---|---|
| | | Online Pretest / 18 May 2001 (*n* = 21)[b] | Online Posttest/ 25 June 2001 (*n* = 23)[b] |
| 1 | A gene is from parents/grandparents | 11(52%) | 15 (65%) |
| 2 | A gene determines a trait / characteristic | 5 (24%) | 21 (91%) |
| 3 | A gene affects cell development | 3 (14 %) | 0 (0%) |
| 4 | A gene is/part of a chromosome | 3 (14%) | 9 (39%) |
| 5 | A gene is / part of DNA | 2 (10%) | 1 (4%) |
| 6 | A gene is information | 2 (10%) | 1 (4%) |
| 7 | A gene is a trait/characteristic | 1 (5%) | 0 (0%) |
| 8 | Genes are related to meiosis | 0 (0%) | 1 (4%) |
| 9 | Genes are related to fertilisation | 0 (0%) | 1 (4%) |
| 10 | Genes are affected by environment | 0 (0%) | 1 (4%) |
| 11 | Don't know | 1 (5%) | 0 (0%) |

[a] One student could have more than one conception.
[b] 20 Participating students took both online tests.

Each respondent could give several conceptions of the gene in the online tests. For instance, Nelly posted the following in the online pretest on 18 May 2001:

> Genes have something to do with chromosomes which you receive from your parents and ancestors. They are passed down through generations but may change when different people are introduced each time.

As can be interpreted from her posting, she held two gene conceptions (see categories 1 and 4 in Table 4.5). Analysis of the class-wide online test data of participants (*n* = 23) and student responses of student interviewees (*n* = 7) both indicated that their gene conceptions before and after instruction did change but did not progress to a level of sophistication expected of Year 10 science in Western Australia (Hackling & Treagust, 1984; Venville & Treagust, 1998).

As can be seen from Table 4.5, most (over 50%) of the students' gene conceptions were about the gene being an entity passed from their parents (category 1). They usually referred to the observable characteristics (phenotype) they inherited from their parents rather than genes (genotype) as something that determine such characteristics. Eye and hair colours were most commonly used as examples for illustration when students described the genes in the interviews and in the online test postings.

The following quotes are about conceptions of Category 1 from both the pretest and posttest:

> Eleanor: [G]enes are passed down from both parents (Online Pretest/18 May 2001)
>
> Nelly: They are passed down through generations but may change when different people are introduced each time. (Online Pretest/18 May 2001)
>
> Neil: Genes are essential for passing on traits from one generation to the next (Online Posttest/25 June 2001).
>
> Nora: you get your genes from both your parents... (Online Posttest/25 June 2001).

After instruction, 65% of students still held the conception of an inactive-particle gene but two substantial changes (Categories 2 and 4) occurred in their conceptions. First, the percentage of students who held the conception of a gene that determines a trait or an active-particle gene (Venville & Treagust, 1998) increased from 24% to 91%. The following quotes from the students' online test postings represent some of the students' ideas of Category 2 in their online postings:

> Simon: [T]he gene is responsible (sic) for determining cell development and its characteristics; it decides the purpose of the cell (Online Pretest/18 May 2001)
>
> Laurie: A gene is something that gives you certain characteristics. (Online Posttest/25 June 2001).
>
> Neil: Genes determine a persons traits and characteristics. (Online Posttest/25 June 2001).

Second, those who conceptualised the gene as part of a chromosome increased from 14% to 39% as illustrated by more quotes below:

> Nelly: Genes have something to do with chromosomes which you receive from your parents and ancestors. (Online Pretest/18 May 2001)
>
> Nora: [G]enes are made up of chromosomes (Online Posttest/25 June 2001).

Lillian: Genes are made up of chromosomes. You get some characteristics from both of your parents. You see the dominant gene in a characteristic, though there may be a carrier or recessive gene (Online Posttest/25 June 2001).

Other conceptions were not common or did not change much after instruction. For example, three of the students mentioned about genes affecting cell development in the pretest but none of them mentioned this again in the posttest. Two of the students mentioned about genes being information in the pretest but only one did so in the posttest. Overall, the class-wide data suggested that students conceptualised the gene as an entity from their parents, which determines a characteristic but they did not understand how it brings about this. According to the Venville and Treagust's interpretive framework, the students' gene conceptions in School A are generally intelligible, partly plausible, but not fruitful. Before generating another assertion, I explored the gene conceptions of interviewees in depth in the following section.

#### *4.4.3.2 Interviewee Students' Gene Conception Progression*

The online test and interview data of seven students provided more evidence on the preinstructional-postinstructional change in their gene conceptions from an ontological perspective.

Four target students — Eric Laurie, Nelly and Matthew —were interviewed twice, before and after instruction. To the postinstructional interviews, I also invited Ada, Nelly's peer, and Nelson and Mark, a dyad of fast workers who had completed almost all the *BioLogica* activities within the three computer sessions. Except Ada, who was absent for the online pretest, all seven interviewees did both the pretest and posttest so that it is possible to reconstruct a ontological progression of their gene conceptions or mental models (Vosniadou, 1994) before and after instruction. Table 4.6 summarises the ontological pathways of the seven interviewees together with the conception status according to Venville and Treagust (1998) and some sample quotes from either the interviews or the online tests.

The conception status of Matthew warrants a short discussion here. Matthew had the best performance in both the researcher's tests (online tests and interview reasoning tasks) and the teacher's tests. The status of his postinstructional conception of the gene is *intelligible* and *plausible* but not *fruitful.* For example, the following dialogues in the postinstructional interview illustrates the status of his gene conception:

Interviewer: Okay. We come back to the genes. Can you explain to me what a gene actually is?

Matthew: Umm (long pause) I am still a little bit unclear about that but it can either be dominant or recessive. Genes control development in a cell or any cells. Um.. different combinations.

Interviewer: What do you mean by dominant and recessive?

Matthew: Um… I don't really know.

Interviewer: So you mean [the genes] control the characteristics, right?

Matthew: Yeah. They will just give different signals out to where cells are developing.

Interviewer: How do genes affect development?

Matthew: I'm not sure.

As can be seen from the above quotes, Matthew was unable to explain how exactly a gene determines a trait. Therefore his conception of a gene is not fruitful but very close to being so. He mentioned, "They will just give different signals out to where cells are developing" but he was unable to explain how genes affect development. As will be discussed in Chapter 6 about Case Study Three in School C, the high achievers, such as Andrea, were able to explain how the DNA instructions are copied as signals or as messenger RNA to make proteins for controlling the development of cells.

These analyses and interpretations further corroborate an assertion about students' conceptual change along the ontological dimensions related to Research Question 4.6. I generated Assertion 4.8.

*Assertion 4.8*

*On the basis on the change in the students' ontological status of their conceptions, their postinstructional gene conceptions were intelligible, partly plausible but not fruitful.*

Table 4.6

*Ontological Progression and the Status of School A Interviewees' Gene Conceptions*

| Student | Ontological Progression of Gene Conceptions | | | | Sample Quotes (Postinstructional interview/21 June 2001) |
|---|---|---|---|---|---|
| | Passive-particle gene | Active-particle gene | Sequence-of-instruction gene | Productive-sequence-of-instruction gene | |
| Eric | I [a] → | I | | | Eric: A gene tells us what, what type of, what eye colour we have or what type of characteristics we have... If you've got the gene of blue eyes you can see that they've got blue eyes, …an their parents, one of them should have blue eyes. |
| Laurie | I → | I | | | Laurie: … like maybe the parent might have blue eyes and the dad might be just a carrier or not blue eyes … So it happens with all the characteristics as well. …you don't actually see … what in a person like blue eyes, they might carry the gene for blue eyes, but because they've got a dominant gene... |
| Nelly | I → | → | IP [b] | | Nelly: Um, yeah, well the genes, they're like, characteristics of the person, and DNA is the blood, and the chromosomes is, like, I don't know how to explain it...[Genes are] hereditary information. |
| Matthew | I → | → | IP | | Matthew: Yeah. They [Genes] will just give different signals out to where cells are developing. |
| Ada[c] | ? → | → | IP | | Ada: Well, the chromosomes are in the cell and the DNA is the blood that carries the, cells, um, and the genes are, the, well, the chromosomes are the structure. Kind of the DNA. I think. I don't really know about that … Yep. Exactly. The hereditary information. |
| Nelson[c] | I → | IP | | | Nelson: Um... Its part of DNA. It basically makes what people really are. You get genes the same as you parents so you have similarities between yourself and your parents. Genes are part of chromosomes (slight hesitation), which is again part of the DNA … Not sure how to describe it [how a gene produces a phenotype] |
| Mark [c] | I → | IP | | | Mark: Well basically defines whether you are a boy or a girl, what colour hair, skin eyes and what you look like basically…I am not really sure [how a gene produces a phenotype] |

[a] Intelligible. [b] Intelligible-plausible. [c] Ada was absent in the online pretest and Nelson's and Mark's preconceptions were based on their online pretest postings.

#### *4.4.3.3 Ontological Conceptual Change*

According to Chi (1992) and Chi et al. (1994), students have difficulty when learning certain scientific concepts involving radical conceptual change or change one ontological category from matter (things) to processes. This is similar to Vosniadou and Brewer's (1987) knowledge restructuring (see section 2.2.9).

From an ontological perspective, students in School A generally exhibited an ontological change within the ontological category of matter (things) in that they changed from conceptualising the gene as an inactive-particle to an active-particle — both within the ontological category of matter (see Figure 2.8). However, the students did not have any change across the categories from matter to processes as did some Year 10 students in School C (see Chapter 6). In other words, they did not understand that a gene as a set of instructions coded in DNA bases (genotype) for controlling the production of proteins which in turn determine a characteristic (phenotype). In further response to Research Question 4.6, the finding in this section is presented in terms of Assertion 4.9.

*Assertion 4.9*

*Students' ontological conceptual change in their gene conceptions was within the ontological category of matter but not across categories from matter to processes.*

### 4.4.4 Concept Mapping Analysis of Interviewees' Genetics Knowledge

In response to Research Questions 4.6, this section uses concept mapping method (Novak, 1990) to analyse the propositions about the gene and other concepts of genetics of four target interviewees students as individual cases: Eric, Laurie, Nelly, and Matthew. They were initially invited to participate in the interviews on the basis of their pretest results and classroom observations. They represented roughly a continuum across the range of differing prior knowledge of genetics.

#### *4.4.4.1 Concept Mapping Method*

Concept mapping technique (Novak, 1990; Novak, 1996, 1998; Ruiz-Primo & Shavelson, 1996; Wallace & Mintzes, 1990) was used to compare student interviewees' conceptions of the gene based on the propositions they said in the preinstructional and postinstructional interviews. From the interview transcripts, 14 different concepts were identified in the interviewee students' propositions: *genes*, *parents/grandparents/father/mother/dad/mum, children/offspring/kids* (or names of children in interview tasks), *chromosomes*, *DNA*, *fertilisation, meiosis, gametes/sperm/egg, cells*, *development*, *chance*, *dominant* and *recessive*. *characteristics/features/traits/sex* (or examples). As concepts *parents, children* and *genes* were initially provided by the interviewer, they were not counted as new concepts in the concept maps so constructed. Therefore, there were only 11 concepts to be considered as new concepts when students mentioned them in the interviews.

As an example, Eric's first concept map (see Figure 4.5) was constructed using the nine concepts of which only four are new (*chromosomes, sperm/egg, fertilisation,* and *hair/eye colour*) and interconnecting them by the 10 biconcept links identified in the transcript of the preinstructional interview concerning the conceptions of the gene and genetics (see Table 4.7).

Other concept maps were likewise constructed using the same method. The concept maps were reconstructed several times as the interview data were re-interpreted in light of changes in the coding and/or the categories in the iterative processes of thinking, reading more literature, conversations with others and further analyses.

#### *4.4.4.2 Comparing Interviewees' Pre/Post Concept Maps*

I have tried out a simple analysis of the changes in the each student's preinstructional and postinstructional concept maps using two criteria partly based on the concept map literature (see for example, Hoz, Tomer, & Tamir, 1990; Wallace & Mintzes, 1990). The first criterion is the number of new concepts[22] related to the concept of the gene which an interviewee mentioned in the interview. The second one concerns the links between any two concepts (biconcept links between the gene concept and other concepts or between other concepts) which an interviewee mentioned during the interview. Links between varieties of one concept, e.g., parents/father/mother, are counted as one. The analysis is shown in Table 4.8.

[22] The terms "concepts" and "conceptions" follow the definitions given in Chapter 2 section 2.2.3.

Table 4.7

*Propositions used in Constructing Eric's First Concept Map*

| Eric's Propositions about the Gene (based on preinstructional interview transcript) | First concept (s) | Second concept(s) | Link | Label |
|---|---|---|---|---|
| With the genes you have um... your father has certain genes and so does your mum have different genes as well, and then they're put together so it makes Pierre [name of children in the interview task] from the parents. | Parents | Genes | Have | 8 |
| | Parents, genes | Pierre | Put (genes) together to make | 2 |
| They [genes] transfer chromosomes, and um.... And they usually have things like X and Y, and so X and X can be a female and um….” | Genes | Chromosome | Transfer | 1 |
| The genes come from the sperm and the egg and then they join together | Genes | Egg and sperm | Comes from | 3 |
| | Sperm | Egg | Join together in | 4 |
| Um.... When they [parents] have sex from intercourse and you have the sperm meet the egg and fertilization occurs and then there is Pierre [name of a child in the interview task] | Parents | Fertilisation | Have sex from intercourse | 9 |
| | Sperm and egg | Fertilisation | Meet in/join together in | 4 * |
| | Fertilisation | Pierre | Then there is | 5 |
| It determines likes um...hair colour, eye colour. | Genes | Hair colour, eye colour | Determine | 6 * |
| So if the father has blue eyes, and so does your mother, then you [Pierre] probably have more blue eyes than brown. Um... | Parents | Eye colour | If both (parents) have (blue eyes) | 10 |
| | Eye colour | Pierre or a child | Probably blue eye in | 7 |

* Three-way links.

Table 4.8

*Comparison of the Pre- and Post- Concept Maps of Four School A Interviewees*

| | Total number of new concepts | | Total number of valid biconcept links | |
|---|---|---|---|---|
| | Preinstructional map | Postinstructional map | Preinstructional map | Postinstructional map |
| Eric | 4 | 4 | 10 | 14 |
| Laurie | 4 | 4 | 8 | 8 |
| Nelly | 7 | 8 | 12 | 12 |
| Matthew | 9 | 11 | 14 | 15 |

As can be seen from the data in Table 4.8, the students with lower prior knowledge (Eric and Laurie) mentioned less new concepts than those with high prior knowledge (Nelly and Matthew). The number of links between the concepts also follows roughly the same pattern but Eric appeared to have mentioned more links than expected. Constrained by the thesis length, I can only include Eric and Matthew's concepts maps here. Eric and Matthew's concept maps, when scrutinised in detail (see Figures 4.5 to 4.8) not only indicate their cognitive structure or declarative knowledge about the gene in terms of propositions (Novak, 1998) but also the interconnections between the gene conceptions and other conceptions about genetics. Such connectedness can be an indicator of their relational understanding (Skemp, 1976) of genetics. Although the concept maps constructed from the interview transcripts cannot fully capture students' conceptions, each pair of an interviewee's concept maps do display consistent case-specific patterns over time.

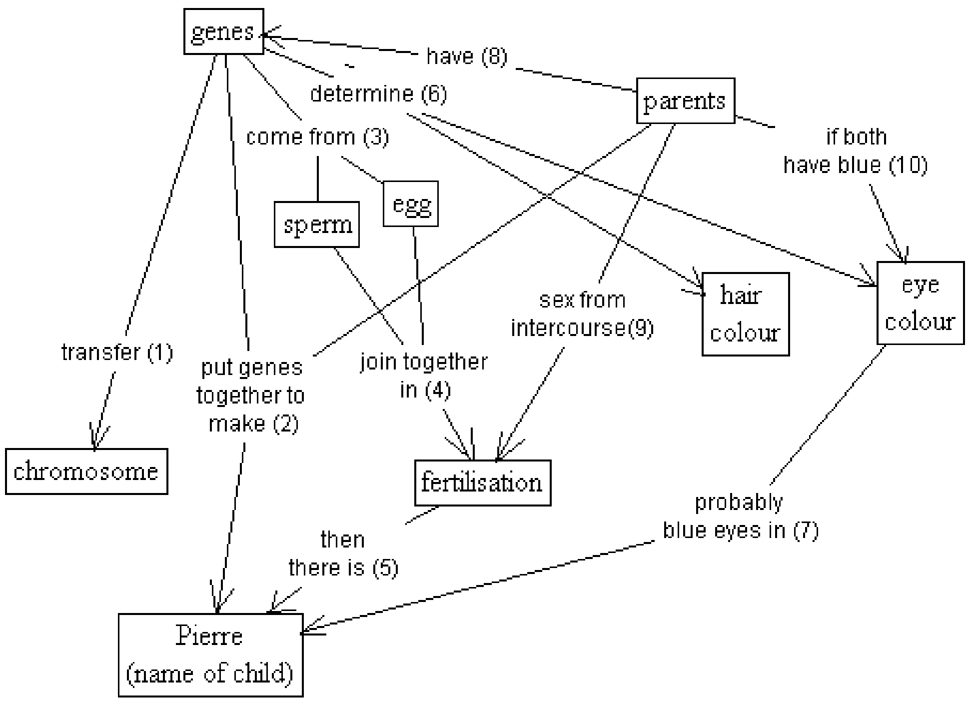



*Figure 4.5* Eric's first concept map based on preinstructional interview transcript (21 May 2001).

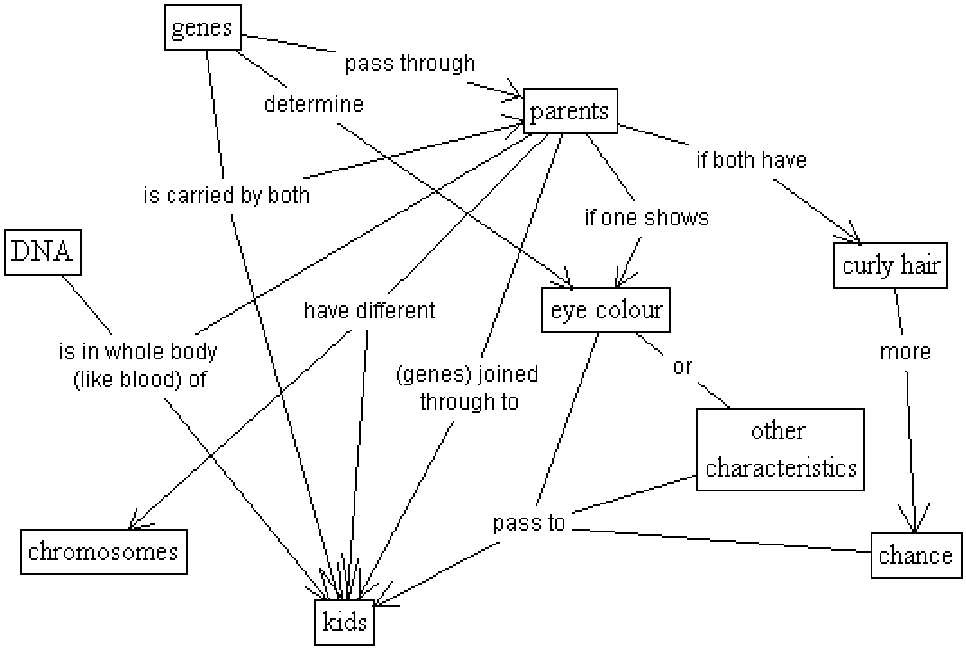



*Figure 4.6* Eric’s second concept map based on postinstructional interview transcript (21 June 2001).

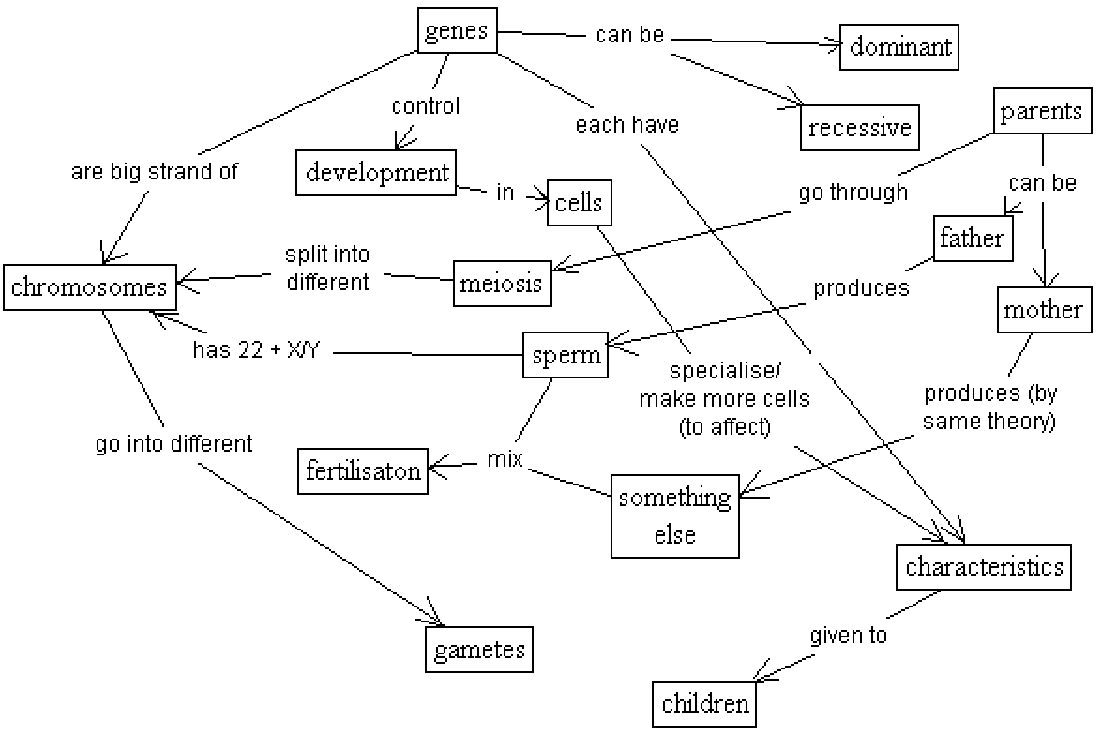



*Figure 4.7* Matthew’s first concept map based on preinstructional interview transcript (29 May 2001).

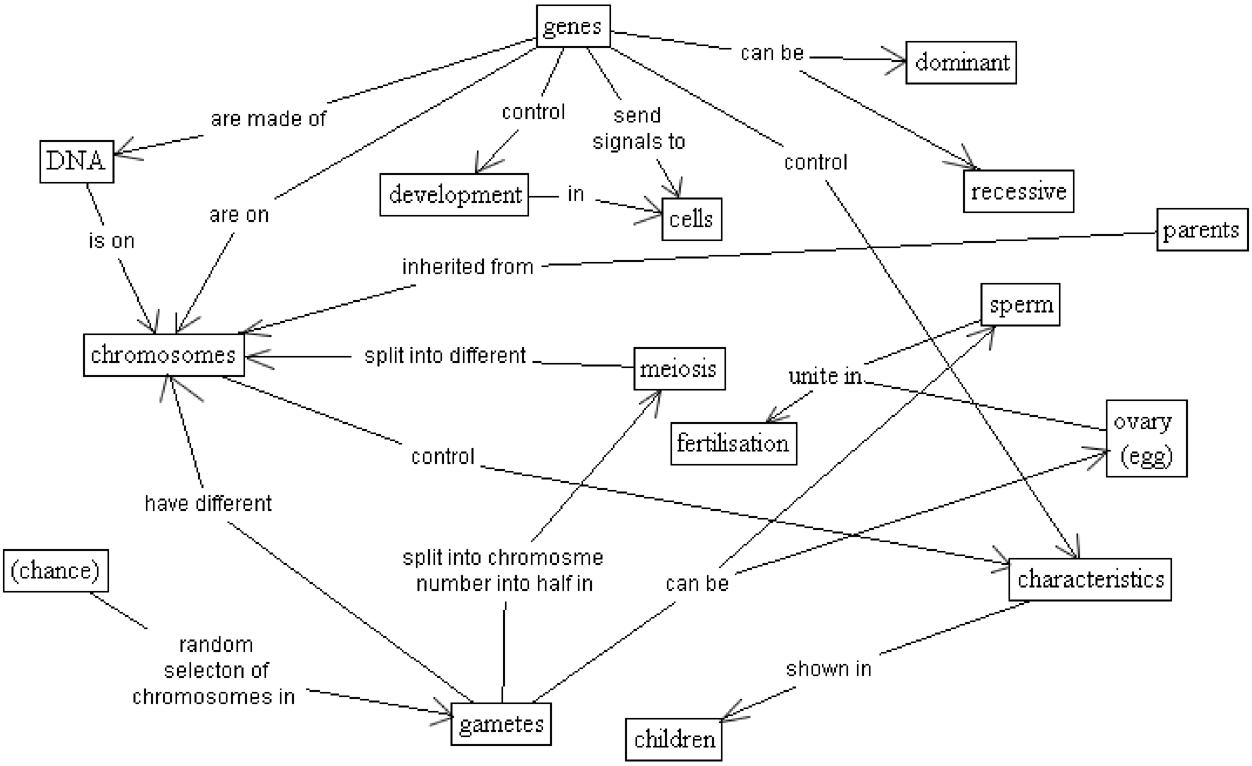



*Figure 4.8* Matthew's second concept map based on postinstructional interview transcript (19 June 2001).

The structure of Eric's concept maps is generally simpler, and has lower connectedness in their cognitive structure compared to Matthew's. This pattern is consistent with their prior knowledge and understanding of genetics from other data sources such as the reasoning tests and interview tasks. For Matthew, his second concept map (see Figure 4.8) had new concepts DNA and chance, both linked directly or indirectly to genes, chromosome and meiosis. One of Matthew's propositions—that about the random selection of chromosomes by chance in determining the characteristic—is more process-based than matter-based (Chi et al., 1994). The higher connectedness of Matthew's concept maps also indicates that he had better relational understanding (Skemp, 1976) of genetics. However, Matthew's postinstructional concept map still did not correspond to a sophisticated gene conception, i.e., *a productive sequence of instructions*, according to Venville and Treagust (1998, p. 1049). He did progress in his gene conception by relating the gene to three other concepts—information, DNA and meiosis—which are important components for developing a sophisticated gene conception. However, the status of his postinstructional conception of the gene can only be ascertained as being intelligible and plausible but not fruitful. The concept maps provide more supporting evidence for Matthew's ontological progression discussed in section 4.4.3.2.

As discussed in section 4.4.3.3, both the class-wide online test data and target student interview data indicated that students' ontological conceptual change was within the category of matter but none of them conceptualised a gene as a process (see Assertion 4.9). The concept map analyses in this section provide more supporting evidence for Assertion 4.9 because even for Matthew, the high achiever, his postinstructional concept map did not clearly explain how a gene works as a set of instructions.

## 4.5 Mr Anderson's Reflections and Comments

On reflection, despite Mr Anderson's reservation about students' learning outcomes other than the motivational aspects, he still thought that *BioLogica* was useful for learning genetics, particularly the challenges in the activities. He said in the postinstructional interview: "It's a simple program and it's good for the kids. Once the kids have got the hang of it then they need the challenges at the end and the challenges were things that were probably more useful to them."

### 4.5.1 Two Useful *BioLogica* Activities

Mr Anderson believed that two useful *BioLogica* activities were *Meiosis* and *Monohybrid*

After all the teaching, Mr Anderson said that he had made the right choice in using *BioLogica*. Consistent with his expectations in the preinstructional interview, he reiterated that he used the activity *Meiosis* because of the visualisation effects and the interactivity, which he found "hard to simulate" in the classroom. He said:

> Maybe the meiosis one [*BioLogica* activity] was useful because they could actually follow the process of meiosis um.. they could see the process of meiosis, they could see the fertilization process and the end product which was good. That is hard to simulate in the class. That's the only reason I would use the program would be to show them that (Mr Anderson / Postinstructional Interview)

The second *BioLogica* activity he had expected to be useful was also found in practice to be so, particularly the instant feedback for students to see the process and results quickly without having to imagine.

> The crosses section [*BioLogica* monohybrid activity], I could do the same in the class. The only thing they got out of that was doing the crosses and getting an instant feedback. They could see it and that was probably the comment they made, that they could actually see the process and the end result very quickly without having to imagine it (Mr Anderson/Postinstructional Interview)

### 4.5.2 Enjoyment but Not Much Learning

As for the students' achievement, Mr Anderson had reservations whether students had really learnt anything about genetics from *BioLogica* besides having fun and enjoyment when he told me in the postinstructional interview, "The kids enjoyed the change of using the computers but I don't think they learnt anymore with the computer than without it. It was just nice for them to have a break [from my usual teaching]."

In contrast to having rather high expectations of students learning from *BioLogica*, Mr Anderson reflected that the time used in using the program for fun could be less effective than normal classroom teaching and learning. He said:

> Yeah. They might like it. I would like to know how much they gained from using the Dragons over what they could have done in the classroom. It's alright having fun but how many of them have actually used it and learnt from the program itself. There is a lot of difference[s] from that. You know playing or working with the Dragons, but how much do they actually learn from it? That is a totally different thing. Two totally different questions.
> (Mr Anderson/Postinstructional Interview)

At the same time, he did not feel comfortable with students starting to learn genetics such as family trees (pedigrees) without prior classroom teaching. From my observation, he did not have the time to look at the scripts in the two activities that are designed to guide and interact with the students' keyboard responses. As such, he taught about crosses at length the day before students were engaged in the *BioLogica* activity *Monohybrid*. He said in the postinstructional interview, when talking about the *monohybrid* activity:

> How they would have gone without the pre-preparation I don't know because they wouldn't have had a clue how to do the family tree without pre-working um... but having given them that pre stuff every kid finished the work. (Mr Anderson/Postinstructional Interview)

As discussed in section 4.4.1, Mr Anderson's students had different perceptions. Some of them found whole-class discussion, when they had to copy "heaps of notes"(Laurie/Preinstructional Interview) rather boring. Some wished to use *BioLogica* activities more often and thought that they really learnt something from the interactions with the Dragons. *BioLogica* activities were intrinsically motivating to many students. Analysis of other sources of data suggested that most students did progress in genetics reasoning but whether or not *BioLogica* contributed to this could not be ascertained from this case study. From my observations, most of the students really enjoyed the three computer sessions but they had not been adequately guided through the activities to tie them to what was being taught in the classroom.

### 4.5.3 Mr Anderson's Suggestions

If the busy life of Mr Anderson is rather typical of science teachers in Western Australian schools, his comments and suggestions should be useful to other busy teachers who wish to use *BioLogica* in teaching of genetics. Indeed, before the research, I did devise a table to suggest the possible use of the different *BioLogica* activities but was unable to involve practising teachers to give me input. Therefore, what he suggested was exactly what I wished to do in collaboration with the teachers.

In the postinstructional interview, he commented that the program was not teacher-friendly and made a number of suggestions that he thought would be useful for teachers and students to use *BioLogica*. He made three suggestions which I gratefully appreciated: (1) a worksheet for students to "jot down something"; (2) an information sheet for students; and (3) a teacher's guide to the *BioLogica* activities.

Mr Anderson's first suggestion concurs with the notion of an *online notebook* proposed by the *BioLogica* developers and researchers at the Concord Consortium (Christie & Horwitz, in progress). The online notebook is to provide "repeated opportunities for students to make their learning explicit and to receive feedback" (p. 4) that can be saved and reviewed at any time" (p. 5). In response to his second and third suggestions, I created some web pages in my website *BiologicaOz* as reference material for students and teachers in other case schools. Mr Anderson's comments and suggestions prompted me to provide a sheet with the Dragon's genome to the teachers and to the students in Schools C and D. His third suggestion was actually heeded, though not actually, by the Concord Consortium software developers in that a *BioLogica* teacher's guide (Concord Consortium, 2002) became available online to teachers in 2002. Ms Elliott, the participating teacher in School D (Case Study Four) used this guide for planning her teaching with *BioLogica* (see Chapter 7).

## 4.6 Summary of Findings

Drawing from analysis, interpretation, and discussions of data from multiple sources in the preceding sections, nine assertions have been formulated in the above sections. They provide some answers to the original seven research questions and some other questions that emerged during the research. As 24 of the 33 students in the class participated in the study and all the data were collected from these participants, the findings therefore refer to the participating students only. Nonetheless, it should be noted that the opinions, comments or perceptions voiced by Mr Anderson and the student interviewees referred to the teaching and learning of the whole class. The following summarised the findings in terms of the assertions in response to the six relevant research question(s) (See Table 4.9). I will discuss Research Question 4.7 separately in a following section.

Assertion 4.1

Mr Anderson integrated *BioLogica* in his classroom teaching as a supplement as he expected the program's visualisation and instant feedback to engender student motivation and understanding.

Assertion 4.2

Mr Anderson implemented *BioLogica* it to provide students drills and practice of what he had taught in class.

Assertion 4.3

The major barriers in using *BioLogica* in Mr Anderson' classroom were the time constraints, knowledge about the program, and technical issues

Assertion 4.4

Many students, personally interested in genetics, found *BioLogica* intrinsically motivating because of the salient features of *BioLogica* MERs (situational interests).

Assertion 4.5

Student motivation appeared to affect their decision to learn, their task engagement, and their interactions with the MERs.

Assertion 4.6

Some students were able to improve their genetics reasoning because of the role of multiple external representations (MERs) of *BioLogica* in constraining their interpretation of the phenomena of genetics

Assertion 4.7

Students' improvement in their genetics reasoning was only for the easier types even though they were actively engaged in *BioLogica* activities.

Assertion 4.8

On the basis on the change in the students' ontological status of their conceptions, their postinstructional gene conceptions were intelligible, partly plausible but not fruitful.

Assertion 4.9

Students' ontological conceptual change in their gene conceptions was within the ontological category of matter but not across categories from matter to processes.

Overall, teaching that included *BioLogica* activities as a supplement brought about some conceptual change in student learning along the ontological, epistemological and affective/social dimensions, with the change along the last dimension being the most significant. However, students' gene conceptions were just intelligible, to some extent plausible, but not fruitful.

Table 4.9

*Summary of Assertions Mapped to Research Questions in Case Study One*

| Research Questions | Assertions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 | 4.9 |
| RQ4.1 How does Mr Anderson integrate and implement *BioLogica* in his classroom teaching of genetics? | √ | √ | | | | | | | |
| RQ4.2 What are Mr Anderson's beliefs, referents, and actions in the integration and implementation of *BioLogica*? | | √ | | | | | | | |
| RQ4.3 What are the major barriers to using *BioLogica* in Mr Anderson's classroom? | | | √ | | | | | | |
| RQ4.4 What are the factors from the social/affective perspective that influence students' interaction with the computer-based MERs in *BioLogica*? | | | | √ | √ | √ | | | |
| RQ4.5 Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? (Do they exhibit conceptual change from an epistemological perspective?) | | | | | | √ | √ | | |
| RQ4.6 What are the students' gene conceptions before and after the lessons that include *BioLogica*? (Do they exhibit conceptual change from an ontological perspective?) | | | | | | | | √ | √ |
| RQ4.7 Is there any relation between the students' conceptions of genetics and their genetics reasoning? | | | | | | | | | |

As regards Research Question 4.7 to which no assertions are mapped in Table 4.9, by synthesising the analyses of the preceding sections, there appeared to be a relation between the students' gene conceptions and their genetics reasoning although no assertions are directly related to this research question. Class-wide online data except Nelly's case indicated that those who had more sophisticated gene conceptions did better in their genetics reasoning tests. Nelly had a rather sophisticated gene conception but she was the only student in School A who regressed—from a pretest score of 50% to posttest score of 33%—in the parallel two-tier items in the online tests (see Appendix 1, Table A1.4.3). I tried hard to articulate the available evidence but could not find a plausible explanation for this disconfirming evidence. Nelly was probably not a mindful learner when she was engaged in the *BioLogica* activities but unfortunately the only log file about her computer usage available was the one about the activity *Monohybrid* in which she shared with Eleanor (see Appendix 1, Table A1.4.2).

## 4.7 Limitations of Case Study One

Despite the findings in terms of the assertions given in the preceding section, there are several limitations of this study.

First, the technical issues affected the installation of the program and affected student use of the program. Second, there was only limited collaboration between the teacher and the researcher and Mr Anderson's busy school life did not allow more regular conversations to reflect upon the ongoing research. Third, I was unable to collect all the log files because of the limited access to the computer room and other technical problems with the computers. Fourth, the impact of using *BioLogica* on the learning of students allowed me to generate an assertion but there was not enough supporting evidence to conclude how much the students' interaction with *BioLogica* MERs had contributed to their learning.

## 4.8 Discussion and Conclusions

The findings in the first case study of this research in School A are significant in a number of ways. They have allowed me to examine in detail what the positive and negative issues are likely to be in an authentic classroom situation where the teacher used an interactive multimedia program in teaching and learning of genetics. The multidimensional conceptual model (Tyson et al., 1997) has proved to be a robust framework for analysing and interpreting the complexity of classroom teaching and learning in this case study.

As I could not have further member-checking with Mr Anderson at the time when I was writing the thesis, I have tried to be cautious and parsimonious in interpreting Mr Anderson's beliefs and referents in his actions using *BioLogica* or the MERs as a supplement in his teaching of genetics in this study. As such, I believe my cautions and parsimony can make this thesis more commensurate with the qualitative research tradition reviewed and discussed in Chapters 2 and 3.

Given that appropriate use of representations is likely to be instrumental in increasing the intelligibility of difficult scientific concepts such as the gene. Intelligibility is the first step towards plausibility and fruitfulness in the progression to more sophisticated conceptual learning. The findings in this study indicate that the students in School A did not have a sophisticated conception of the gene or the "productive sequence of instructions gene" (Venville & Treagust, 1998, p. 1040) even after instruction. Accordingly, the students' gene conceptions can be ascertained as being at most intelligible and plausible but not fruitful. However, as reviewed in Chapter 2 section 2.2.6.1, a more powerful way of determining students' conceptual status is to use Thorley's (1990) *status analysis categories.* Thorley's categories take into consideration metaphysical beliefs that refer to the ontology of an object as a consistency factor for increasing the plausibility status and power and promise as status elements for fruitfulness (see Table 2.3). Thorley's framework of status analysis was used in other case studies and will be reported in the remaining results chapters (Chapters 5, 6 and 7) and the cross-case analysis chapter (Chapter 8) about students' conceptual learning.

Overall, Case Study One provided a cornucopia of data from multiple sources useful for analysis and interpretation in understanding of the *how* and *why* besides the *what* research questions about the case. Mr Anderson's expectations, reflections, critiques, comments, and suggestions are also useful sources of information for improving the ongoing research in the case schools that followed. Given the limitations of this study discussed in the preceding section, it can be concluded that the learning outcomes of the teaching and learning of genetics in this case study generally matched the expectations of both and teacher and the researcher. The third type of protagonists in this research, the students, obviously benefited in one way or another in this new way of learning genetics and learning with the latest computer technology. But with a small sample of participating students, even the data from multiple sources can only provide some supporting evidence for the assertions generated thus far. Although the assertions were in response to the research questions, the findings reported here are far from being conclusive regarding the contributions of the MERs of *BioLogica* to students' development of genetics reasoning. Nevertheless, the computational perspectives have enriched my understanding of the ways which Mr Anderson used and could have used multiple external representations (MERs) in classroom teaching. At the same time, negative issues identified in this case study informed me in improving the ongoing research in the case studies in other schools. The next chapter will be about the case study of a preservice teacher in School B.

# Chapter 5

# Case Study Two:

# Teaching Genetics with Multiple Representations as a Preservice Teacher

## 5.0 Overview

This chapter is about Case Study Two which focused on the teaching and learning experiences of a preservice teacher in School B. Before her field teaching experience, Miss Bell (pseudonym) tried out *BioLogica*, examined her own genetics knowledge, and thought about how the *BioLogica* could be used in classroom teaching and learning of genetics. During her practice teaching in a Year 10 class in School B, she prepared, taught and reflected upon her teaching of genetics and evolution that included the use of *BioLogica*. While the major focus of this chapter is on the role of teacher knowledge in teaching a difficult topic with information and communication technologies (ICT) in a science classroom, the preservice teacher's reflections, collaboration with the researcher, and classroom contexts are analysed and interpreted through narrative stories or vignettes.

## 5.1 Theoretical Framework

The theoretical framework in Case Study Two utilised the multidimensional conceptual change model (thereafter called CCM) (Tyson et al., 1997) for interpreting learning. Other perspectives were also used, in particular, the interpretation of the classroom discourse that incorporated computational perspectives (Ainsworth, 1999; Ainsworth et al., 1997), social constructivist ideas (e.g. Driver et al., 1994) and sociolinguistic views (Lemke, 1990, 1998a) (see Chapters 2 and 3). Further, the literature on teacher knowledge reviewed in this chapter was also an important source of reference for the theoretical framework for this case study.

I now present a brief review of the literature on teacher knowledge specifically related to this case study. Over more than a decade, Shulman's (1986) model of teacher knowledge incorporating the construct of pedagogical content knowledge (PCK) has had an important impact on teacher education. Shulman (1987) defined PCK as "that amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8) and stated as follows:

> [Pedagogical content knowledge] represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners and presented for instruction. (p. 8)

Recent researchers have reconceptualized Shulman's classical definition of PCK in light of new studies. For example, on the basis of a review of literature, particularly that of Grossman's (1990) work, Putnam and Borko (1997) discuss PCK as comprising the following four aspects:

a) overarching conception of teaching a subject;
b) knowledge of instructional strategies and representations;
c) knowledge of students' understandings, thinking, and learning in a subject; and
d) knowledge of curriculum and curricular materials." (p. 1233)

More recently, Loughran, Milroy, Berry, Gunstone, and Mulhall (2001) reconceptualised PCK as being "the knowledge that a teacher uses to provide teaching situations that help learners to make sense of particular science content"(p. 289).

Despite some recent studies about the preservice teachers' learning to use technology in teaching various subject areas (see for example, Beyerbach, Christie, & Vannatta, 2001; Lawless, Smith, Kulikowich, & Owen, 2001; Pope, Hare, & Howard, 2002), studies on the pedagogical content knowledge (PCK) of teachers using ICT in teaching science remain a largely uncharted area of research. On revisiting the literature, I found that my notion is most similar to the *Learning to teaching Technology Model* (Friedrichsen, Dana, Zembal-Saul, Munford, & Tsur, 2001)—a model developed in Pennsylvania State University used in a teaching team's project entitled "pedagogical content knowledge for using technology to support scientific inquiry (PCK-Tech for SI)" (p. 377).

## 5.2 Methods

In line with this research, Case Study Two utilised an interpretive, multiple-case embedded design (Erickson, 1998; Gallagher, 1991; Merriam, 1998; Yin, 1994) as explained in detail in Chapter 3. Within the methodological framework of this research, I now describe, in the following sections, the case-specific methods in data collection, analysis and interpretation.

When Case Study One in School A was in progress, one issue that arose was that Mr Anderson, a very experienced biology teacher, found the interactive program *BioLogica* difficult to use and understand. This issue provoked me to think of a *sensitising question* (Strauss & Corbin, 1998) of what the data might indicate. My original idea was to study how preservice teachers understand the software and how they plan to use it in their teaching. I called for student teachers or preservice teachers to participate in my proposed case study through personal contacts to publicise my proposed study in one Western Australian university. A preservice teacher, Miss Bell, soon e-mailed me and volunteered to participate in the study because she said she was interested in the *BioLogica* program. Miss Bell tried out the software and later invited me to School B where she had her practice teaching.

As in other case studies, the teacher's voice is here highlighted and contextualised narratives such as vignettes are included in reporting the research findings as discussed in Chapter 3 section 3.6.5. This is in keeping with an increasingly important trend of reporting research about teaching and teacher education in Australia (see for example, Loughran, Mitchell et al., 2001; Wallace & Louden, 2000).

### 5.2.1 Specific Research Questions

As this case study took place immediately after the first case study in School A, only very preliminary findings from the first case study were available for informing me to progressively focus my study (Stake, 1995). Initially, Case Study Two appeared to be different from Case Study One but obviously my research experience working in School A did help my work in School B. I tried to rethink about the initial six research questions (see Chapter 3) in relation to the unique school context in School B and what I had known about Miss Bell and her experiences and the requirements for her practice teaching.

Based on the emergent design in case study methodology (Merriam, 1998), the following specific research questions 5.1 to 5.4 were developed from the initial research questions (see Chapter 3) to guide this case study as follows:

RQ5.1 How does a preservice teacher's knowledge affect her integration and implementation of *BioLogica* activities in teaching and learning of genetics?

RQ5.2 What are the preservice teacher's beliefs, actions and referents in integrating and implementing the teaching of genetics with ICT?

RQ5.3 What impediments does a preservice teacher encounter when implementing *BioLogica* activities in her teaching?

RQ5.4 Does the preservice teacher's knowledge of genetics undergo conceptual change with respect to teaching genetics as a school subject?

The first two specific research questions, developed from the first initial research focus (see Chapter 3), were similar to those used in Case Study One except that they highlighted the preservice teacher's knowledge. The third question was to address the expected impediments affecting how a preservice teach may use innovations in a new school environment. As only limited data were collected, I shifted my focus to looking at whether conceptual change took place in Miss Bell's learning to teach genetics with technology. This was guided by the fourth research question. Such conception is similar to Putnam and Borko's (1997) "overarching conception of teaching a subject" (p. 1233), the content knowledge of genetics in a special type of pedagogical content knowledge (PCK) for teaching the subject with a special multimedia program. Data from each of the multiple sources were collected in response to one or more of these research questions as will be described and explained in the subsequent sections (see Table 5.1).

Table 5.1

*Mapping Research Methods to Research Questions in Case Study Two*

| Research Question | Data Collection Method (V = verbal data; N = numerical data) | | | | Source (T= teacher; S=students) |
|---|---|---|---|---|---|
| | Online Tests | Interviews / E-mail discussions | Observations | Documents | |
| RQ5.1How does a preservice teacher's knowledge affect her integration and implementation of *BioLogica* activities in teaching and learning of genetics? | N, V | V | V, video data | V (teaching scheme, time-table, handouts etc.) | T |
| RQ5.2 What are the preservice teacher's beliefs, actions and referents in integrating and implementing the teaching of genetics with ICT? | | V | V, video data | V (teaching scheme, time-table, handouts etc.) | T |
| RQ5.3 What impediments does a preservice teacher encounter when implementing *BioLogica* activities in her teaching | | V | V | | T |
| RQ5.4 Does the preservice teacher's knowledge of genetics undergo conceptual change with respect to teaching genetics as a school subject? | N, V | V | V | V (hand-outs, reflective journals) | S[a], T |

[a] Only three students took the online test (similar to a posttest) in response to Miss Bell's call for them to do the tests at home.

### 5.2.2 Miss Bell and School B

Miss Bell, born and educated in Western Australia, was a full-time student teacher enrolled in a Postgraduate Diploma of Teaching in one university in Western Australia during this case study. While trying out the *BioLogica* and the online tests, it happened that she was to teach genetics in Year 10 science as her next field experience. Subsequently, Miss Bell invited me to the school to observe her lessons and support her in using *BioLogica* in teaching as part of the research.

School B, a state co-educational senior high school was located in a suburb near a national forest park about 25 km from the Perth city centre. Established in the earlier 1980s and recently managed by a strong leadership team, the school provided a caring learning environment that fostered excellence in all areas and conducted quality programs across the curriculum with an emphasis on technology in teaching.

However, as Miss Bell told me, the science department had yet to integrate technology into teaching and learning. Eventually, all 28 Year 10 students (11 boys and 17 girls) taught by Miss Bell during her practice teaching participated in the research with their parents' consent. These students, aged 14 or 15 at the time of the research, mostly had English as their first language.

In 2001, Miss Bell graduated from her university with good results and has been teaching in a country senior high school in Western Australia since the beginning of 2002.

### 5.2.3 Data Collection

The data collection in this case study took place in two phases. In the first phase, I worked with Miss Bell while she was trying out the software in May 2001 whereas the second phase of data collection took place in the school where she had her field experience.

In the first phase, Miss Bell visited our Science and Mathematics Education Centre (SMEC) once or twice a week in May 2001 to try out the *BioLogica* software and the online material and samples of online tests on genetics reasoning (see Chapters 3 and 4). She discussed with me in meetings or via e-mail communications about the educational potential of the interactive program and talked about how she would plan to use the program in her teaching. As she tried out three *BioLogica* activities *Introduction*, *Rules* and *Mutations*, the analysis of the log files that tracked her interactions with the *BioLogica* program provided me with feedback concerning her conceptions of genetics and how she used the program.

The second phase took place in the school where she had her practice teaching. Miss Bell prepared, taught and reflected upon her teaching and learning of genetics, and tried to teach with *BioLogica*. Six of Miss Bell's ten lessons generating field notes were observed and reflective journals of some lessons collected. Four lessons were audiotaped, two lessons were videotaped and all were fully transcribed verbatim. Besides collecting some documents in the school relevant to Miss Bell's teaching, I interviewed Miss Bell before and after the three weeks of teaching and had a meeting with her for "member checking" (Guba & Lincoln, 1989, p. 241) one month later (see Table A1.5.1 in Appendix 1 for the chronology of research progress). As Miss Bell only taught a small part of the topics about genetics and evolution, no attempts were made to compare students learning before and after instruction. As such, the teacher interviews were called first and second interviews instead of preinstructional and postinstructional interviews as in other case studies. We also shared some of our reflective journals and discussed the classroom teaching via e-mail communications throughout and immediately after her teaching practice in School B. Table 5.1 maps the research questions to the research methods.

Due to constraints imposed on the field teaching experience of a preservice teacher and the tensions of a busy school life, it was not possible to collect some sources of data as initially planned, especially data about students' learning outcomes. I was unable to interview the participating students. For moral and ethical considerations, I made Miss Bell's interests as the highest priority while collecting data. Further, I tried to minimise the researcher's intrusion in the classroom life and to respect the wishes of Miss Bell, her supervisor teacher and students of the school.

### 5.2.4 Data Analysis and Interpretation through Narratives

While Miss Bell was grappling with her knowledge in preparing and teaching genetics, a topic which she did not know well, she endeavoured to organise and use ICT in her teaching in a school where science teachers had limited experiences in integrating ICT in their teaching. In so doing, Miss Bell had to make the best use of her personal knowledge and what she had learnt from her university studies to achieve her planned goals.

To illustrate how Miss Bell developed these components of her PCK, I use four narrative vignettes to report the findings (see section 3.6.5). Each vignette is entitled with a direct quote from Miss Bell's voice concerning one aspect of PCK. Shulman's terminology is mentioned where necessary to link the interpretation to the research literature. Based on the analysis in each vignette, I report the finding in terms of an assertion. Finally, a section on PCK sums up the findings.

## 5.3 First Vignette: "I think it's a difficult subject"

On 2 May 2001, having confirmed she would participate in the research, Miss Bell came to see me in our education centre to try out the *BioLogica* activities and the online tests. This meeting marked the beginning of Miss Bell's learning to teach genetics.

In a brief conversation, Miss Bell told me that she was very interested in genetics but her science degree did not include a formal course on genetics. Before she started to use the *BioLogica* program, she helped in trying out the first of several samples of the online pretest on genetics reasoning which would be used by students in the research. In response to an open-ended questionnaire item in the pretest she did on that day, she wrote, "I have not taught genetics, but I am interested in learning more about genetics and teaching it in the future." Then, as she had to hurry back to her university for some lectures, she promised to send me feedback by e-mail later that week.

On the following day, she e-mailed me as follows:

> I think it [*BioLogica*] is a great tool. I like how the students can work at their own pace using this application. A few comments. I think students should be encouraged to take notes while using this application, by doing this the students will feel more confident when answering the questions. The application relies a lot on memorising what you have just read/learnt from the last pages. I also think that if the program had sounds like "well done", "that's correct", "your moving along great" etc. this kind of motivating and encouraging reinforcement would be beneficial, the students really need that reinforcement. I had no problems logging on to *BiologicaOz* [website with online material], I will try the next quiz on Friday. I hope my comments are helpful. (Miss Bell/E-mail /3 May 2001)

As can be seen in Miss Bell's e-mail about her first impression of *BioLogica,* she already identified *flexibility,* one of the three salient features of *BioLogica,* as did most teachers and students in other case schools (see Chapter 4). She appeared to think about how computer-based learning could motivate learners within a behaviourist perspective (i.e., related to extrinsic feedback) but she actually thought of intrinsic motivations first identified in Case Study One. In the first interview when I asked her about her beliefs in using technology in teaching and learning of science, she said:

> I think it's vital. In these days kids seem to know everything about computers and they [computers] are in our lives anyway so they need to know how to use them. They are fun and kids like to do fun things. They tend to learn more.
>
> (Miss Bell/First Interview/11 June 2001)

Her suggestion of asking students to take notes was also shared by other teachers like Mr Anderson (see Chapter 4) and Ms Elliott (see Chapter 7) as a useful strategy for students learning with *BioLogica*.

Since that session, Miss Bell had tried out several versions of the online pretest on the genetics reasoning while trying to learn more about *BioLogica*. She also browsed through the information about genetics on the website which I created for classroom use in the research. The results of these tests were interpreted to identify Miss Bell's conceptual understanding of genetics, and, in particular, genetics reasoning (Hickey & Kindfield, 1999). Analysis of her online test results indicated she did not have a strong content knowledge of genetics.

First, she might not have fully understood the process of meiosis and its role in gamete formation, and, in particular, about ploidy and independent assortment of alleles during the process. Second, she also may have problems in using some types of genetics reasoning such as Type IV (effect-to-cause across generations) (see Table 3.1). Third, like most students in other case studies in this research, her conception about the genes was not sophisticated in that she conceptualised the gene as matter (a thing) more than a process (Venville & Treagust, 1998) (see the analysis Appendix 1, Table A1..5.3).

Initially, Miss Bell found teaching difficult with her limited content knowledge of genetics. The teaching of genetics is even more difficult for her because she was to start in the middle of the students' learning of the unit *Biological Change* (Education Department of Western Australia, 1987). Perhaps what Miss Bell said in the first interview after she had taught for a few lessons reflected how she had been grappling with her teaching and learning of a conceptually difficult topic. She said:

> Well, I think it's a difficult subject. It's very hard to explain to the kids just by words and diagrams. So I am hoping when we start using *BioLogica* that it's going to sink in easier. I can say at the moment that the kids are finding, especially meiosis, very confusing. They are asking me lots of questions and they are trying to understand it.
>
> (Miss Bell/First Interview/11 June 2001)

Given that she thought genetics is confusing and difficult to explain in words and diagrams, particularly the dynamic process of meiosis, the interactive computer program *BioLogica* instantly appealed to her as a visual way of explaining meiosis. She then articulated her thoughts as follows:

> Purely I would really like them to get something out of the Meiosis activity. They are struggling to get to grips with this topic. It might just be me because I am an inexperienced teacher; I might not be explaining it well enough. So I am hoping they will get something out of the Meiosis activity.
>
> (Miss Bell/ First Interview/11 June/2001)

Miss Bell had been studying some ICT courses in her university as part of her Postgraduate Diploma of Education study and had a high level of computer literacy; and, like the participating teachers in other case schools, she identified the salient features of the interactive multimedia program. However, her understanding of the functions of multiple representations (Ainsworth, 1999) in interactive multimedia was limited.

*Assertion 5.1*

*As a preservice teacher,* Miss Bell *did not have a strong content knowledge for teaching genetics, nor did she have a rich repertoire of instructional strategies; however, she had a high level of knowledge skills in ICT upon which she could build her pedagogical knowledge for teaching genetics with BioLogica.*

## 5.4 Second Vignette: "I will get more confident with time and practice"

One month on, I observed Miss Bell's lesson on 6 June 2001. On that day, I did not know that the lesson was the very first one Miss Bell had ever taught in a classroom until she told me later.

When I arrived at School B, Miss Bell was still busily preparing for the lesson in the staff room. I followed her to her classroom and at the door they were greeted by Mr Nicholson (pseudonym), Miss Bell's supervisor teacher in School B, whom I met the previous week. Then, the 26 students were entering the classroom; 10 boys and 16 girls were present. The lesson was a successful debut for Miss Bell. She used one workbook activity for students to find out their own genetic traits to illustrate discontinuous variation, one hands-on activity for measuring height and weight to illustrate continuous variation, and finally she summed up the lesson with some notes on the white board for students to copy. According to Lemke's (1990) analysis, the classroom talk on that day was a mix of "Teacher Monologues"(p. 49) in which the teacher present material and some "Triadic Dialogues" (p. 8) pattern in which the teacher asks a question, called on students to answer it, and then evaluates their responses. There were very few "Student Questioning Dialogues" (p. 52) in which students ask the teacher questions. Despite a few hard questions being asked, as might be expected from a first lesson with this class, Miss Bell was naturally under stress and did not have a lot of confidence during those initial lessons. On the following day, I could not visit School B, as I had to interview students in School A. In response to my e-mail message later that day, she wrote:

> Thank you very much for your feedback and reflection on my lessons. I need as much feedback as possible to help me become a better teacher. I am very nervous at the moment, but I will get more confident with time and practice (Miss Bell/E-mail/7 June 2001)

Then when I asked her about her teaching about meiosis on that day in the second e-mail message, she replied to say that said she did not explain the meiosis process well:

> The lesson today was on meiosis. I'm not sure how well it went. I don't think I explained the process too well. I am hoping that when they use *BioLogica* they will understand it better. (Miss Bell/ E-mail/ 7 June 2001)

My interpretation of this comment about her teaching was that she did not appear to have a strong content knowledge upon which she could construct the necessary pedagogical content knowledge in teaching about meiosis. Actually she told me later that she did use the overhead projector to show a diagram of the meiosis process but the students did not find that so useful (see Figure 5.1).

In the overhead projection transparency (OHT) (see Figure 5.1), she had included a large amount of detail and the esoteric names of the stages of meiosis, which other experienced teachers do not usually teach in their Year 10 classes. It was likely a copy from a textbook.

Three weeks later, she reflected on this lesson:

> I first just went over about gametes and that meiosis only occurs in the male and female gonads. Then I went briefly over the process and then I put on a big overhead of all the different divisions and slowly went through each process. It is quite confusing so I think you need a few lessons to go through it. (Miss Bell/Second Interview/25 June 2001)

Dissatisfied with her teaching about meiosis, Miss Bell looked forward to using the *BioLogica* activity *Meiosis* in the lesson on the following day. However, she was not able to use the computer program until two weeks later. She ended the second e-mail message of 7 June 2001 by saying "Teaching is very stressful when you are just a prac teacher."

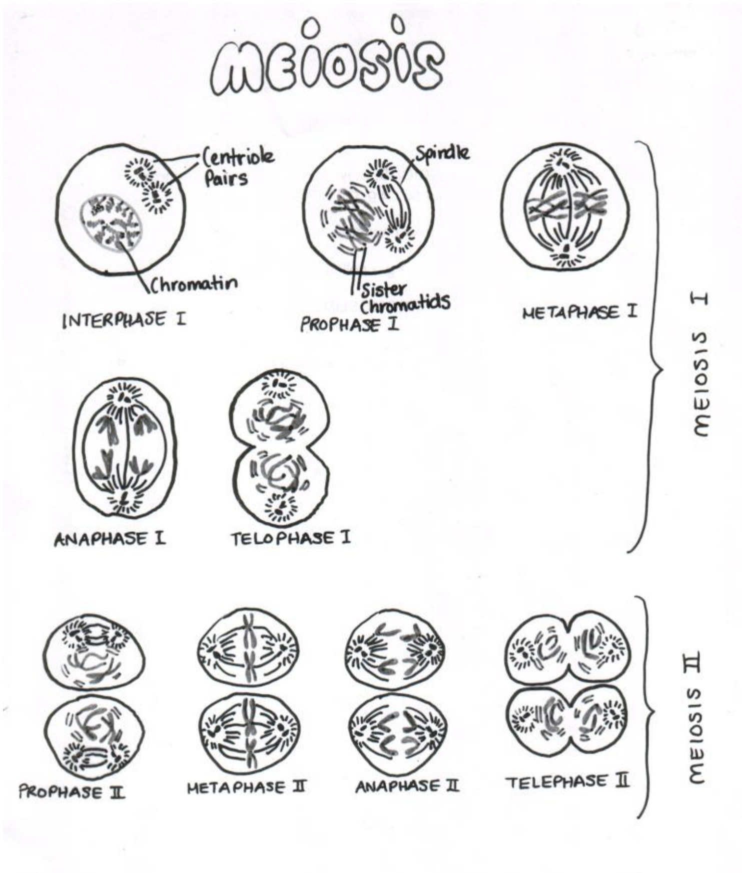



*Figure 5.1* Overhead projection transparency used by Miss Bell in the lesson on meiosis (7 June 2001).

The above vignette portrays how a preservice teacher struggled to teach for the first time and to teach a difficult topic genetics. Miss Bell wished to harness the multiple representations of *BioLogica,* more specifically the computer Dragons—a constructed entity—as a resource for explaining (Ogborn et al., 1996) meiosis.

Meiosis, the cell division during the formation of gametes (sperm or eggs in humans), has been well documented to be one of the most difficult parts of genetics to teach and learn in school (Kindfield, 1994; Lewis, Leach, & Wood-Robinson, 2000; Stewart et al., 1990). What turned out to be a poignant message to preservice teacher educators was the remark in her e-mail about teaching being “stressful”. I agree with Roth and Tobin (2001) who pointed out, “prospective teachers continuously experienced the gap between what was required of them in the ‘idealistic ways’ of their university courses versus teaching in the classroom” (p. 745).

On 12 June 2001, in the second week into Miss Bell’s practice teaching in School B, she taught a very interesting but challenging lesson on the inheritance of human eye colours. Miss Bell’s Year 10 science lesson started at 8:40 am. As usual, I followed Miss Bell to the science classroom. Girls and boys were still waiting outside the classroom talking rather noisily. When they were seated, I noticed there were 17 girls and 10 boys. Mr Nicholson was in the classroom most of the time while Miss Bell was teaching.

Soon Miss Bell started to teach. First, she tried to link students’ thinking to what she had taught about variation on 6 June by asking them to suggest some examples. The interactions were typically of a *Triadic Dialogue* pattern (Lemke, 1990). Then, she moved to the next part of the lesson by showing two OHTs (see Figures 5.2 and 5.3) about the inheritance of eye colours. Miss Bell’s *Teacher Monologue* (Lemke, 1990, p. 49) with the two OHTs being projected in sequence caused some agitation in the class. Students tried to look at each other’s eyes. Unlike the science textbooks[23] which oversimplify eye colour as being either blue or brown, Miss Bell’s teaching about the inheritance of eye colour appeared to captivate the students’ interest. Students might think that their teacher’s explanation for the nine phenotypic classes (see Figure 5.3) resulting from the interaction of four pairs of genes (see Figure 5.2) was closer to the real-life situation as they had all these different eye colours.

A boy, who always asked questions, started a *Student Questioning Dialogue* as follows:

Student: Do my parents need to have brown eyes if I have dark brown?

---

[23] Such as Anderton’s (1990) *Fundamental Science Book 4* for Year 10 science.

Miss Bell: Yes, they will most likely have brown eyes.

(Miss Bell's journal / 12 June 2001)

Then, the class became rather noisy as they had to work in groups of two to find out the eye colours their offspring would have by imagining they were parents.

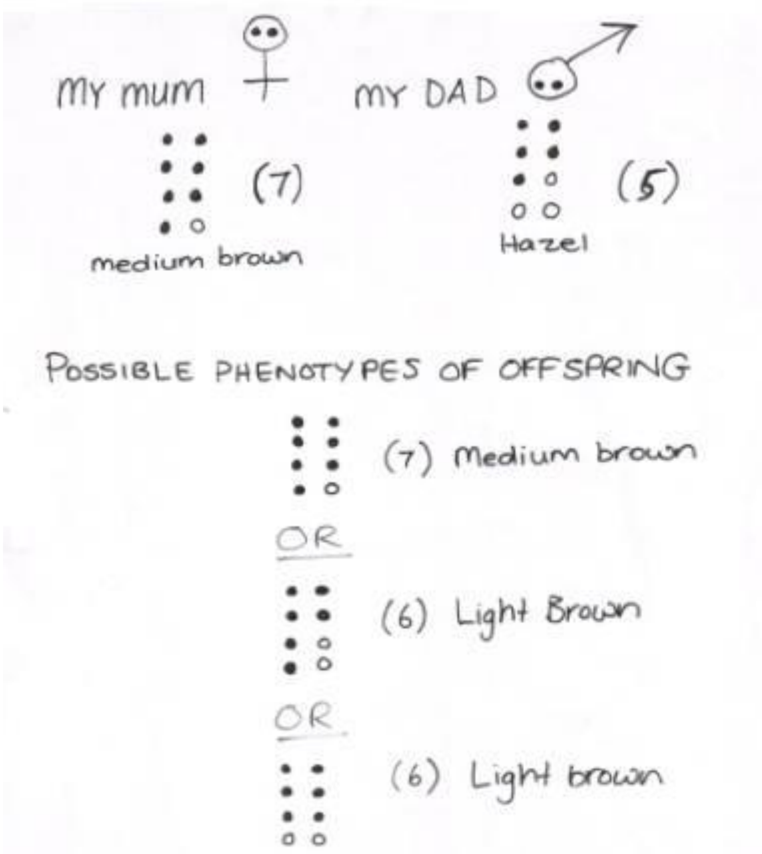



*Figure 5.2*. Miss Bell's first overhead projection transparency used in the lesson on 12 June 2001.

Next, three groups volunteered to present on the white board their results which were similar to Figure 5.2. Their *offspring* were predicted to have eye colours along a continuum from light blue to dark brown. Miss Bell commented briefly on their results.

Then the same boy started another *Student-Questioning Dialogue* (Lemke, 1990) question as follows:

Student: You say there are only eight different colours. How can you call it continuous variation?

Miss Bell: I was only giving an example. There are really many other shades of eye colours. I was categorising the major colours.

(Miss Bell's journal/12 June 2001)

| NUMBER OF CONTRIBUTING EYE COLOUR ALLELES | PHENOTYPE |
|---|---|
| 8 | Dark Brown |
| 7 | Medium Brown |
| 6 | Light Brown |
| 5 | Hazel |
| 4 | Green |
| 3 | Grey |
| 2 | Dark Blue |
| 1 | Medium Blue |
| 0 | Light Blue |

*Figure 5.3* Miss Bell's second overhead projection transparency used in the lesson on 12 June 2001.

The boy appeared to be dissatisfied with the answer but Miss Bell had no time to continue with this conversation. She turned to the white board to summarise what she thought students needed to know by writing: "Variation is due to the type of inheritance controlled by multiple genes or multiple alleles" (my field notes/12 June 2001). Students were invited to suggest some ideas and come to the front to write them on the white board. Students, especially the girls, were very enthusiastic in suggesting and writing their ideas on the board.

At 9:40am, less than 10 minutes before the end of the lesson, Miss Bell was about to finish her lesson saying "Any questions? Please. No questions?" when the hard question came. One boy had just asked a question and the teacher was talking to him when two other boys raised their hands. Miss Bell came over to them. One boy asked a question that made the whole class laugh. Then, the class became rather noisy and Miss Bell said, "Last five minutes please listen." The lesson soon ended and the boys and girls began to leave the classroom. Miss Bell told me that the boy asked her to explain why a man can have one brown eye and one blue eye, and that he said that he read about it somewhere.

On the next day, Miss Bell gave the class an Internet URL address[24] and explained to the class that the man with one blue eye and one brown suffered from Waardenburg Syndrome (named after a Dutch doctor who discovered it), which is an inherited disorder often characterized by varying degrees of hearing loss and changes in skin and hair pigmentation. The students were happy to know the answer. Miss Bell probably thought that the boy's hard question was meant to be a trick for her.

After her field teaching experience, when asked if she had any difficulties in her very first teaching experience, Miss Bell said:

> I didn't find any real difficulties except that the kids were so bright and were asking some very hard questions that I did not know and I had to go home and research myself about the question. I sometimes would spend hours on the Internet especially about the one blue eye and one brown eye. So this was probably the hardest part and it was quite embarrassing not being able to answer some of their questions. (Miss Bell/Second Interview/25 June 2001)

In the above vignette, it can be seen that the hard question asked by the student was about one uncommon genetic disorder which other experienced teachers may not have known about. It may not be fair to judge a new teacher's content knowledge with this example. However, the Waardenburg Syndrome asked by the student did bring to the fore how Miss Bell used her PCK in teaching genetics. Miss Bell was able to expand her knowledge in response to students' learning demands and she used her ICT skills to improve her teaching.

*Assertion 5.2*

*As Miss Bell was dissatisfied about her teaching in the first few lessons, she endeavoured to harness technology for better representation of genetics and to expand her own content knowledge of genetics.*

---

[24] The updated URL address of this website is at http://www.nidcd.nih.gov/health/hearing/waard.asp

## 5.5 Third Vignette: "I think it would be easier if I was a qualified teacher"

On Thursday 14 June 2001, the end of Miss Bell's second week of practice teaching, the students were to do their online test and to start to use the *BioLogica* activity *Meiosis*.

One week earlier, she taught about meiosis but was dissatisfied about her explanation. She had actually wished to let the students engage in the *BioLogica* activity *Meiosis* the next day but was unable to use the computer room until the following Thursday. Miss Bell e-mailed me on the previous day that it would be useful if I could be in the school earlier. Because of the technical issues in a previous case school, I went to see Mr Smith (pseudonym), the IT person, two weeks earlier to discuss with him about the installation of *BioLogica* and handed him a CD-ROM with the software. However, I was unable to see him again on the previous day to ensure that students could use the program when Miss Bell had the lesson in the computer room. Nor could Miss Bell and I have access to the computer room to try out the program and the online material. Teachers were too busy but Miss Bell told me that Mr Smith had promised to install *BioLogica* in all machines before Thursday.

The lesson soon started in the computer room. All students could successfully log on to access their virtual classroom which I had created in collaboration with Miss Bell on the website at Curtin University. They could read all the pages but somehow they were unable to use the online pretest. Miss Bell talked to Mr Nicholson but could not find Mr Smith. Then, next, students could not run the *BioLogica* program because it had not been installed. Miss Bell discussed with me and decided that students could use the discussion forum and use other web-based material about genetics. The students were already exploring the different functions in the virtual classroom. For the next half hour, the students were totally absorbed in the discussion forum, enjoyed the activity, and posted more than 150 articles but very few of such writings were about genetics. Some postings were jokes or threats to other students. Miss Bell tried to post a few questions to guide their discussion but was unable to lead the discussion. Mr Nicholson appeared to be unhappy about what had happened. In one of Miss Bell e-mails on that day, she reflected on that day's experience:

> I think now that the students have had their fun they should be more responsible. We will soon see… I get very frustrated and stressed out. I think it would be much easier if I was a qualified teacher as I could control the students more, and I would have more authority over them. As I am a guest in the school too, I must do what I am told. I will email you tomorrow to tell you how we will use *BioLogica* after talking to Mr Smith.
>
> (Miss Bell/E-mail/14 June 2001)

She again revealed her stressful feeling and became frustrated when the teachers in the school were too busy to help but she understood she was just a guest.

The above vignette shows that Miss Bell's teacher supervisor and Mr Smith were too busy to arrange for Miss Bell to use the interactive multimedia program as often as she had wished to. Eventually, Miss Bell was only able to use computers in two lessons including one with *BioLogica* activities.

Finally, on 21 June 2001, a Thursday in the third or the last week of Miss Bell's practice teaching, she had a very rewarding lesson having the students engaged in two *BioLogica* activities *Introduction* and *Meiosis* (see Figure 5.4 for a snapshot of *Meiosis*). Miss Bell was glad that the program worked perfectly with no glitches. Mr Nicholson, who had never used the computer in teaching science, walked around the computer room looking at what the students were doing and talked to some of them.

At the start of the lesson, Miss Bell first briefed the class on how to run the program. She then moved around to answer the students' questions and discussed with some group of students. The following is a dialogue captured by the videotape at 12:21 am when two boys tried to get their teacher's attention:

> Student: I killed one of the Dragons.
>
> Miss Bell: That's fine. Work out what the lethal genes are.
>
> Student: How do I do it?
>
> Miss Bell: Go back [to the previous screen] to remember what the genes were. Take some notes about each Dragon.

.

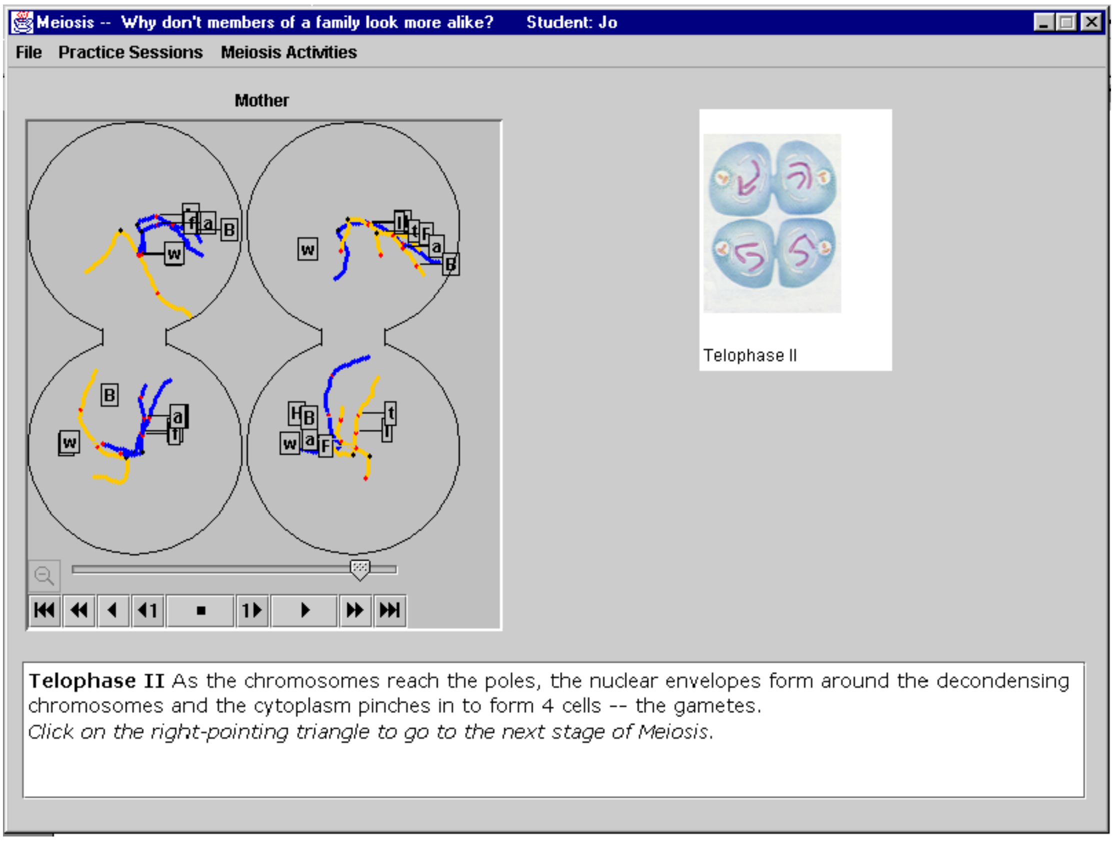



*Figure 5.4* Snapshot of the *BioLogica* activity *Meiosis* graphically showing the meiosis process by animation with accompanying textual explanation.

At 11.28am, the teacher reminded some girls that they could talk to each other and help each other through the activities. Video-recording that started at 11.29 am showed that one girl interacted with *BioLogica* in following dialogues in the text boxes:

> *BioLogica* Question: What did you notice as you examined the chromosomes?
>
> Student's answer: The male had an X and Y chromosome, and the female has two X chromosomes.
>
> *BioLogica* Question: In particular, how do the chromosomes of the male and female Dragons differ?
>
> Student answer: The male Y chromosome had less genetic information than the females X chromosomes. (Video Images / 21 June 2001)

At 11.30am, two girls asked the teacher about dominant and recessive genes. She reminded them that if they could not remember they could go back to previous screens to refresh their memory.

My interpretation is that Miss Bell could have provided better scaffolding to the students while they were engaged in the *BioLogica* activities in the computer room if she had conceptually linked the computer representations (Dragon genetics) to her classroom teaching (human genetics) as did experienced teachers in other case studies (see Chapters 4, 6 and 7).

*Assertion 5.3*

*Miss Bell's implementation of BioLogica activities to teach genetics for understanding was impeded by two kinds of factors: (1) institutional factors such as the cooperating teacher being too busy to support her use of technology and (2) epistemological factors associated with her teacher knowledge.*

## 5.6 Fourth Vignette: "[T]hey need to be guided through"

Overall, the computer session on 21 June 2001 was a success at least in motivating students to learn about the dynamic process of meiosis. Probably, the students were able to relate genetics reasoning to meiosis in solving problems but little data about students' learning outcomes were collected. Observation of the lesson on 21 June indicated that Miss Bell implicitly used the metaphor of the teacher as a guide in the computer learning environment. In the second interview, she responded when asked what role she thought a teacher should play in the computer room where students were using *BioLogica* activities:

> From my own experience in observing some computer classes the teachers sort of just say log on to your computers and they let the kids do their own work without any guidance. The students need some timing and restrictions and they need to be guided through. Otherwise they will just have fun and not learn anything. So the teacher does play an important role. You can't just think the computers are going to look after the kids and be their teacher. You have to be a teacher as well. (Miss Bell/Second Interview/25 June 2001)

On reflection, Miss Bell found using the *BioLogica* activity *Meiosis* plausible for teaching meiosis. When teaching of meiosis in the classroom she had once tried to use visual aids (see her OHT in Figure 5.1) to help understanding but did not find it so useful (see First Vignette). Miss Bell wished to use the program the next day after she had taught meiosis in the classroom as she said in the second interview, "I think it would have been good to use *BioLogica* the very next day." The reality was that she needed to wait for two weeks before she could use the program and this created problems for her and the students in that their computer activities were not so closely aligned to their classroom learning

After the field teaching experience, Miss Bell described and reflected upon her practice teaching in terms of helping students to understand the meiosis process through visualising what is going on:

> Yes, especially the Meiosis activity. I found the kids really beginning to understand the whole process when doing the activity with *BioLogica*—they could really see what was going on. It was all falling into place when they were using *BioLogica*.
>
> (Miss Bell/Second Interview/25 June 2001)

Miss Bell e-mailed me on 23 June that she had spoken to two girls after the lesson. They told their teacher that they enjoyed using *BioLogica* and it was very helpful in their understanding of meiosis. These two students did the online test (a version similar to the posttest) with good results. A few comments from other students were similar in that the visual process of the dividing cells was very useful. Miss Bell also highlighted the social and affective dimension of learning. She commented about the lesson on 21 June 2001 when students used *BioLogica* activities for the first and the only time as follows:

> I think it [Meiosis activity] worked very well. It was good in the fact that there was a few students moving through the activities very quickly and it was good that they could move on at their own pace. They were asking lots of questions, so it was provoking, a lot of questions. They were interacting well together. So I think it worked out very well.
>
> (Miss Bell/Second Interview/25 June 2001)

When I asked her what the students were discussing while using the program she said:

> Most were commenting on meiosis and the visual representation of meiosis. They were really playing around with that. They liked how they could make their own babies [*BioLogica* Dragons]. (Miss Bell/Second Interview/25 June 2001)

As for student learning, she believed they did learn from the *BioLogica* activities *Introduction* and *Meiosis* as she said:

> In general, I think they learnt something from me. By using *BioLogica* it gave good revision to the students as it went over previous classes. I think by using *BioLogica* it would have been good revision as they have a test next week.
>
> (Miss Bell/Second Interview/25 June 2001)

Despite some initial frustrations, Miss Bell enjoyed her experience in using *BioLogica* and the online virtual classroom in her teaching and thought that both she and her students really learnt about genetics in a different way.

*Assertion 5.4*

*Miss Bell's decision about instructional strategies was underpinned by a learning perspective commensurate with social constructivist ideas as indicated by the metaphor of the teacher as a guide in the computer classroom.*

## 5.7 Conceptual Change of Miss Bell in Teaching Genetics

Despite not having strong content knowledge about genetics, as the four vignettes (sections 5.3 to 5.6) have showed, Miss Bell learnt together with her students when teaching genetics in an innovative way that was unprecedented in School B to which she was assigned for practice teaching.

From the conceptual change perspective guided by Research Question 5.4, I analysed and interpreted the change in her conception of teaching genetics as a subject (Putnam & Borko, 1997) from the three dimensions of the conceptual change model (CCM). In the following analysis, the term *conception* refers to Putnam and Borko's "conception of teaching a subject" (p. 1223) unless it is specified otherwise.

### 5.7.1 Status of Miss Bell's Conception of Teaching Genetics

As reviewed in Chapter 2, the epistemological perspective of the original CCM holds that the status of one's conception depends on whether the conception is intelligible, plausible or fruitful to him or her and whether there is dissatisfaction about the conception. In pointing out the difficulty of determining the status of a learner's conception, Hewson and Thorley (1989) asked one question: “What evidence do people give of the status that their conceptions have for them?” (p. 545).

In order to analyse the status of Miss Bell’s conception of teaching genetics (Putnam & Borko, 1997), I used Thorley’s (1990) status analysis categories (see section 2.2.6.1) to identify the categories (see Table 2.3) in the interview transcripts, e-mail communications, classroom discourse, and Miss Bell’s reflective journals in three stages: pre-teaching, teaching and post-teaching for the particular context of this case study.

Before her practice teaching in School B, Miss Bell found her conception intelligible as she was able to represent the genes with examples and language and she considered it as a difficult subject particularly the meiosis process which genetics educators have considered as the most difficult (Kindfield, 1994; Lewis et al., 2000; Stewart et al., 1990). According to Thorley (1990), “representability of a conception” (p. 58) is the criterion for intelligibility (see Chapter 2). Table 5.2 shows an analysis of Miss Bell’s initial conceptions about the gene based on her responses to an open-ended questionnaire item (“What do you know about a gene?”) when she tried out the online test samples:

Table 5.2

*Intelligibility Status of Conceptions of Miss Bell—analysis partly based on Hewson and Lemberger (2000), and Thorley (1990) (see Table 2.3)*

| Miss Bell’s Gene Conception | Thorley’s Intelligibility Status Elements |
|---|---|
| A gene can be dominant or recessive. (Online test/2 June 2001) | +LANGUAGE |
| It [A gene] is a particle on a chromosome and its function is to control characteristic. (Online test/13 June 2001) | +INTELLIGIBILITY ANALOGY |
| A gene determines what trait an offspring will have. (Online/14 June 2001) | +LANGUAGE |

However, her gene conception might not plausible as she said in her online posting on 2 May 2001: “I have not taught genetics, but I am interested in learning more about genetics and teaching in the future.” Further, online two-tier test results showed that she had some alternative conceptions about the gene (see Appendix 1, Table A1.5.2). According to Thorley’s framework, her gene conception was not plausible because it did not have the consistency in understanding which constitutes most of the status elements for plausibility (see Table 2.3).

Miss Bell said in the first interview that because of the lack of teaching experience she was not sure if she could explain the difficult subject to the students and that she hoped the interactive program would better represent genetics in her teaching. From what she told me in our initial meetings at our education centre, she appreciated the possible learning opportunities which *BioLogica* could afford the students learning genetics because of the multiple representations of *BioLogica*.

As Miss Bell's practice teaching progressed in School B, her gene conception underwent changes in terms of status. The hard question posed by the boy on 12 June 2001 about the Waardenburg Syndrome (see section 5.4) made her dissatisfied with her conception which did not appear plausible. By providing the whole class an informative answer based on a named Internet source with an URL address, she substantially raised the plausibility status of her conception as this evoked a *causal mechanism* (see Table 2.3), one of the plausibility status elements (Thorley, 1990). Her experience teaching with *BioLogica* on 21 June 2001 further raised the plausibility status of her conception when she found that the visual-graphical representations she used had enhanced students' understanding of meiosis (see the First and Third Vignettes in sections 5.3 and 5.5). Probably her conception was not fruitful to her at that stage as the busy and challenging practice teaching in School B did not enable her to have more reflection.

After her practice teaching, status analysis suggested that her conception of teaching genetics involving the use of multiple representations became fruitful to her. In the second interview (25 June 2001), I had the following dialogue with her:

Interviewer: You talked about visual aids last time. Is it because of such visual aspect that you wish to use *BioLogica*?

Miss Bell: Yes, especially the Meiosis activity. I found the kids really beginning to understand the whole process when doing the activity with *BioLogica*. They could really see what was going on. It was all falling into place when they were using *BioLogica*. (…)

Interviewer: After trying *BioLogica* with the kids, even though it was for only one hour. What do you think of *BioLogica* as an interactive multimedia program for learning genetics in Year 10 science?

Miss Bell: I think it worked very well. It was good in the fact that there were a few students moving through the activities very quickly and it was good that they could move on at their own pace. They were asking lots of questions, so it was provoking, a lot of questions. They were interacting well together. So I think it worked out very well.

Her reflections here indicate, first, that her conception of teaching genetics with multiple representations had given her POWER (a status element for fruitfulness as shown in Table 2.3 of Chapter 2). Her conception of using the MERs in *BioLogica* to teach genetics—although she did not explicitly mention about multiple representations—worked well in explaining meiosis to the students. Second, *BioLogica*, by virtue of the MERs, explains the meiosis process better than did her teaching on 7 June 2001 using an overhead projection (compare Figures 5.1 and 5.4). According to Thorley (1990), this experience raised the fruitfulness status of Miss Bell's conception because it maps to the fruitfulness element COMPETE (see Table 2.3). Finally, Miss Bell also saw PROMISE (another status element for fruitfulness in Thorley's categories) in her conception for bringing some innovation to School B as she reflected later in the second interview:

Interviewer: It [Teaching with *BioLogica*] can be quite challenging for a science teacher?

Miss Bell: Yes. Mr Nicholson knows nothing about computers. He was really saying that is up to you Ms Bell because I don't know anything about computers so you have to organise it all. So for Mr Nicholson it would be hard but he wants to push the use of computers in the classroom and so does Mr Roger, the Principal, [who] pushes all classes [to use computers.]

Interviewer: So what you have noticed … do you think Mr Nicholson changed a bit? He looked very curious in the computer room [on 21 June 2001].

Miss Bell: Yes he said he was curious. He said the kids seemed very interactive. I think he was quite happy with what he saw.

The status analysis is summarised in terms of Assertion 5.5.

*Assertion 5.5*

*With her dissatisfaction of the initial conception of teaching genetics, Miss Bell was able to attain a high status of a new conception in that it was intelligible-plausible-fruitful.*

### 5.7.2 Miss Bell's Conceptual Change within a Multidimensional Framework

Given the limited scope of an overly cognitive view of conceptual change (see Chapter 2), this chapter warrants a brief analysis of Miss Bell's conceptual change along the social/affective and ontological dimensions within Tyson et al.'s (1997) multidimensional framework. She claimed that she enjoyed teaching even before she began her practice teaching in School B where she had already observed lessons in April 2001. In the first interview, she talked about her interests:

> Interviewer: Why did you choose to be a science teacher?
>
> Miss Bell: Well I have always liked kids. I like science. I did my science degree and I looked for a job and I couldn't find a job so I thought what could I do? Being a science teacher brings all my interests together.

Then after her practice teaching in School B, she reflected upon her experiences and said, "I was quite happy with it overall. At most I probably would have liked to have spent another lesson on meiosis" (Miss Bell/Second Interview/25 June 2001). Then, in a member-checking meeting on 24 July, she told me that she thought it was worth the time in using *BioLogica* during her practice teaching because both she and her students learnt genetics and something new about the learning technologies. I can thus say that Miss Bell had some conceptual change along the social/affective dimension. Although before the study she claimed that she was interested in science and science teaching, she probably became more interested and motivated through her experiences of teaching genetics, especially teaching it with an interactive multimedia program in a real classroom. The positive feedback which she received from the students and Mr Nicholson, the supervisor teacher, probably boosted her confidence in teaching. In 2002, Miss Bell e-mailed from her country school telling me that she found teaching challenging but rewarding and in particular, she enjoyed teaching biology and human biology.

As for her conceptual change along the ontological dimension, the online tests indicated that her conception of the gene, according to Venville and Treagust's (1998) framework, had progressed along the ontological pathway towards being more sophisticated (see First Vignette in section 5.3). However, there was not enough evidence to say more about this as we did not talk about her content knowledge during the interviews. I believe that as soon as her PCK grew during her practice teaching, her gene conception had also become more sophisticated and that she might view genes as matter as well as processes in line with the scientific conception. No assertion is generated for this section.

## 5.8 Change in Miss Bell's Pedagogical Content Knowledge

Related to the Research Question 5.1, there emerged a new finding about the change in Miss Bell's pedagogical content knowledge (PCK) (Shulman, 1986) for teaching genetics with technology. One of the components of this PCK is Putnam and Borko's (1997) conception of teaching genetics analysed in the last section.

I argue that PCK in the current context pertains to an amalgam of two types of content knowledge (genetics and learning technologies) and a special kind of pedagogical knowledge (how to teach genetics with learning technologies in general and *BioLogica* in particular). This notion concurs with Friedrichsen et al.'s (2001) model on learning to teaching with technology. As the four vignettes in sections 5.3 to 5.5 portray, Miss Bell had improved her PCK through the three weeks of practice teaching in which she talked and thought about using *BioLogica* and then actually used it in teaching and explaining the meiosis process. Miss Bell improved her PCK in two ways.

First, as she was sensitive to students' questions and learning for understanding, she was able to expand her content knowledge of genetics and thus the conception of teaching that content knowledge. Not only did she work very hard to read more, she also used ICT to search for new information and communicate with me for feedback. After the field teaching experience, she was also able to reconceptualise her genetics knowledge. Genetics is difficult to teach not just for her but also because "it is still very new and there are new advances and ideas arising" and " continually changing and advancing" (Miss Bell/Second Interview/25 June 2001).

Second, Miss Bell's habitual reflection upon her practice was likely to contribute to her learning as a preservice teacher. Reflection promotes an interplay between a teacher's own personal pedagogical knowledge to general pedagogical knowledge (Morine-Dershimer & Kent, 1999). Accordingly, reflection allows the personal pedagogical knowledge to be broadened and made more objective while pedagogical conceptions are contextualised Reflection thus brings to fruition a new type of knowledge—context-specific pedagogical knowledge useful for guiding teachers' actions and decisions. Drawing on the model of Gess-Newsome (1999) and that of Morine-Dershimer and Kent (1999), I attempt here to portray a possible pathway of Miss Bell's development of her PCK during her field experience (See Figure 5.5).

The flow chart in Figure 5.5 shows how Miss Bell might have developed her PCK. Her *Subject Matter/Content Knowledge* (about teaching genetics with technology) was constructed upon her studies about genetics in school, her reading and learning from different materials including online resources and the researcher's online tests and feedback, and also upon her course work on ICT, her experiences trying out *BioLogica*, and other web-based materials. Her *General Pedagogical Knowledge* was likely built on her course work and the previous field experience of observing lessons. Of particular importance in the flow chart is the juncture *Reflection* that bridged her *General Pedagogical Knowledge* and her *Personal Pedagogical Knowledge*, which she had developed during the practice teaching, and transformed these to *Context-specific Pedagogical Knowledge* (Morine-Dershimer & Kent, 1999). Reflection thus contributed to the construction of a contextualised pedagogy in the development of her PCK. As Wallace and Louden (2000) argued, since Dewey's time, it has been a centre of criticism of teachers lacking in a disposition towards a reflective practice and it is still the case today. I believe that Miss Bell is a fledgling reflective practitioner.

Miss Bell's growth of PCK is now summarised in terms of Assertion 5.6.

*Assertion 5.6*

*Reflection appeared to provide opportunities for Miss Bell to learn from the interplay between teaching theory and teaching practice in developing a pedagogical content knowledge specific to the classroom context for teaching genetics.*

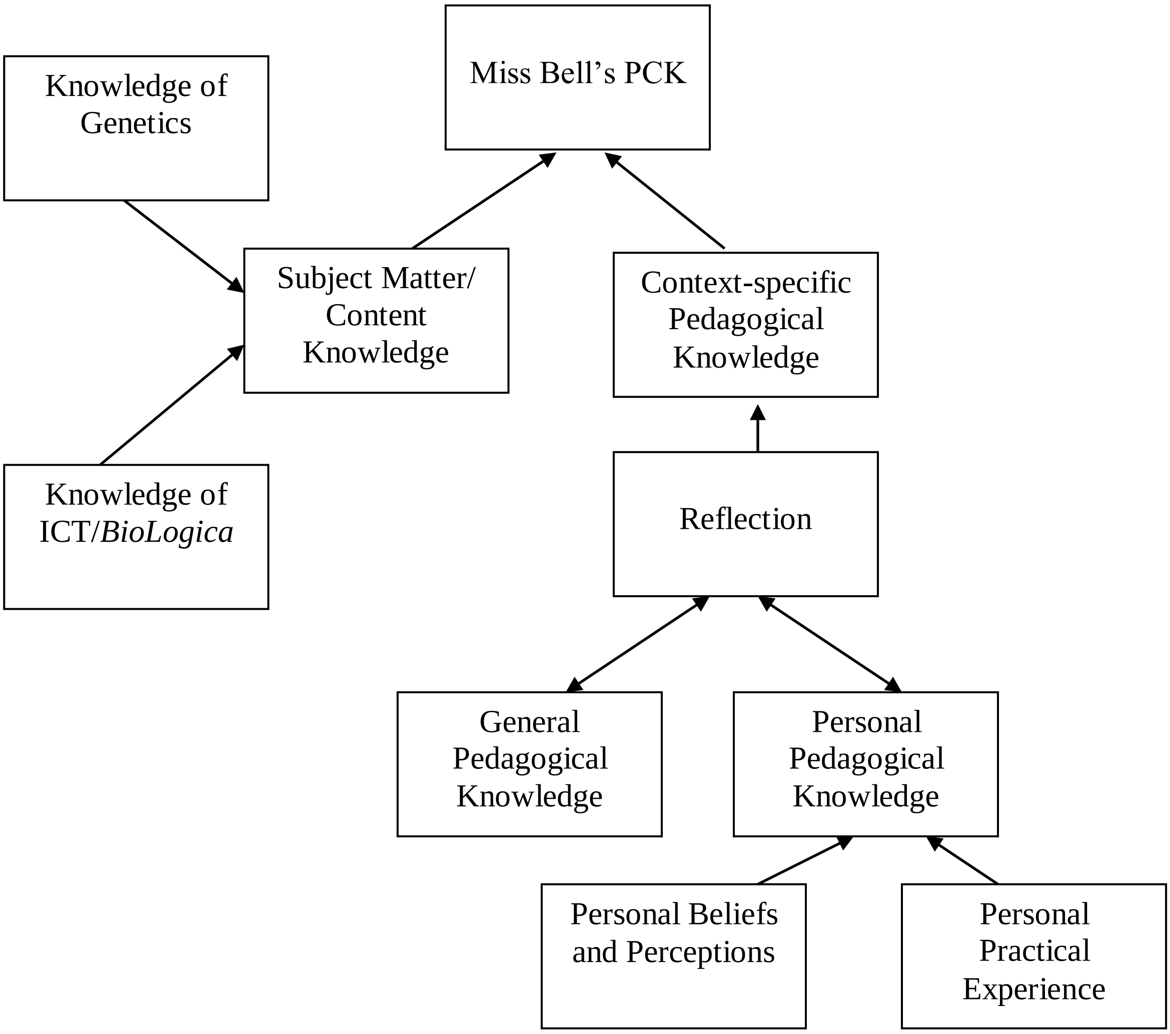



*Figure 5.5* Flow chart showing a possible chain of changes in Miss Bell's PCK; based on Gess-Newsome (1999) and Morine-Dershimer (1999).

## 5.9 Summary of Findings

On the basis of the above data analysis, interpretations and assertions, I have summarised the findings as follows in terms of assertions which were generated in response to the research questions (see Table 5. 3).

Assertion 5.1

As a preservice teacher, Miss Bell did not have a strong content knowledge for teaching genetics, nor did she have a rich repertoire of instructional strategies;

however, she had a high level of knowledge skills in ICT upon which she could build her pedagogical knowledge for teaching genetics with *BioLogica*.

Assertion 5.2

As Miss Bell was dissatisfied about her teaching in the first few lessons, she endeavoured to harness technology for better representation of genetics and to expand her own content knowledge of genetics.

Assertion 5.3

Miss Bell's implementation of *BioLogica* activities to teach genetics for understanding was impeded by two kinds of factors: (1) institutional factors such as the cooperating teacher being too busy to support her use of technology and (2) epistemological factors associated with her teacher knowledge.

Assertion 5.4

Miss Bell's decision about instructional strategies was underpinned by a learning perspective commensurate with social constructivist ideas as indicated by the metaphor of the teacher as a guide in the computer classroom.

Assertion 5.5

With her dissatisfaction of the initial conception of teaching genetics, Miss Bell was able to attain a high status of new conception in that it was intelligible-plausible-fruitful.

Assertion 5.6

Reflection appeared to provide opportunities for Miss Bell to learn from the interplay between teaching theory and teaching practice in developing a pedagogical knowledge specific to the classroom context for teaching genetics.

Table 5.3

*Summary of Assertions Mapped to Research Questions in Case Study Two*

| Research Question | Assertions | | | | | |
|---|---|---|---|---|---|---|
| | 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 |
| RQ5.1How does a preservice teacher's knowledge affect her integration and implementation of *BioLogica* activities in teaching and learning of genetics? | √ | √ | | | √ | |
| RQ5.2 What are the preservice teacher's beliefs, actions and referents in integrating and implementing the teaching of genetics with ICT? | | | | √ | | |
| RQ5.3 What impediments does a preservice teacher encounter when implementing *BioLogica* activities in her teaching | | | √ | | | |
| RQ5.4 Does the preservice teacher Miss Bell have conceptual change with respect to teaching genetics as a school subject | | | | | | √ |

## 5.10 Limitations of Case Study Two

Despite the findings in terms of six assertions presented in the preceding section, there were several limitations of this study.

First, data collection was difficult and incomplete because of the tight time-table constraints and the tensions of increasing the workload of Miss Bell's practice teaching and her teacher supervisor in the school. Second, the lack of enough institutional support—due to the busy life of other teachers in the school—did not allow Miss Bell to use more *BioLogica* activities in her teaching as she has originally planned. Third, due to the reasons given in the first limitation, I was unable to collect data about students' learning outcomes such as interviewing them and collecting their log files. As students were unable to do the online tests in class without prior security arrangements with the IT teacher, only three students did the online tests at home.

## 5.11 Discussion and Conclusions

In interpreting narrative stories of teachers, there are inevitably sources of instability (Wallace & Louden, 2000) that would make the findings contestable. As for "the problem of authenticity" (p. 6), I have tried carefully while writing this chapter to respect Miss Bell's voice and her students' voices by using numerous direct quotes from multiple sources. I believe, as Guba and Lincoln (1989) suggest, that my "persistent observation" (p. 237) of Miss Bell's lessons, my thesis supervisor acting as the "debriefer" (p. 238) in regular discussions of the data analysis and interpretation, and Miss Bell's "member checks" (pp. 238-239) of interview and lesson transcripts, have increased the "credibility" (p. 236) of this case study. However, the findings of this case study have limitations as presented in the preceding section.

The story of Miss Bell in this chapter, illustrated by the four vignettes and other analyses, highlights her change in her conception of teaching genetics and how she developed her pedagogical content knowledge (PCK) while teaching genetics with technology. Miss Bell's story points to a longstanding issue that university programmes do not adequately prepare preservice teachers to meet the diverse demands and challenges of teaching in today's classrooms (see for example, Lawless et al., 2001; Roth & Tobin, 2001; Stuart & Thurlow, 2000). An important agenda in preservice teacher education is to fill the gap between theory and praxis (Roth & Tobin, 2001).

The findings of this case study have some implications for science teacher education and research. First, to help preservice teachers to use ICT in teaching for understanding, teacher education courses should be geared towards a more domain-specific approach to classroom use of ICT. Second, as computer-based multiple representations have provided new opportunities for learning but also present new challenges for teaching, there appears to be a gap in developing teachers' PCK for using ICT in subject areas in teacher education. Consequently, both teacher education and research agendas should put more emphasis on this special type of PCK. Third, with multiple representations becoming ubiquitous in Australian schools, it may be useful for preservice teacher education in the universities to include an introduction to the pedagogical functions of multiple representations or multiple external representations (MERs) — to complement information and processes, to constrain interpretation, and to construct understanding (Ainsworth, 1999; Ainsworth et al., 1997). Lastly, as the literature review indicated, few conceptual change studies have focused on determining the students' conceptual status and rarely were there studies that adopted Thorley (1990) status categories in data analysis, the findings of this study about Miss Bell's conceptual status have some implications for research agendas in science teacher education.

# Chapter 6

# Case Study Three:

# Learning Genetics with Multiple Representations

# in a Laptop School

## 6.0 Overview

Chapter Six describes Case Study Three in two Year 10 classes in School C, an independent girls' school in the Perth metropolitan area. Unlike School A where the access to computers was limited and School B where students had used *BioLogica* only once, School C Year 10 students each owned a laptop computer connected to the Internet in the school through wireless networking. With *BioLogica* installed in their laptop computers, the students had unlimited access to the *BioLogica* activities any time in the classroom or at home. The two participating teachers used *BioLogica* as well as other online multimedia in classroom teaching and learning of genetics. The unlimited access to the *BioLogica* activities and other online resources provided me with valuable opportunities for exploring the potential of using multiple external representations (MERs) in teaching and learning genetics.

A small-scale pilot study was first conducted in one class during Term One (February and March 2002) followed by the main study in the two classes in Term Two (May and June 2002). My collaboration with the two teachers in School C was generally higher than in School A. As in School A, I had the support of the school and the teachers and was able to observe as many lessons as I wished and to interview the teachers and the students. The analysis and interpretation of the wealth of data collected in School C led to findings which were not only unique to this case study but were also comparable on a cross-case basis with the findings in the other case studies. In particular, this study examined the student use of computer-based representations in *BioLogica* and other online multimedia in terms of the functions of MERs in supporting learning and such impacts on their conceptual change.

## 6.1 Methods

### 6.1.1 Research Approach

This case study basically followed the interpretive approach (Erickson, 1986, 1998; Gallagher, 1991) and case-based design with multiple data collection methods (Merriam, 1998) used in the previous two case studies in Schools A and B. The interpretive research method has been as described in detail in Chapter 3.

According to the preference of the participating teachers, Ms Claire and Mrs Dawson (pseudonyms), the website I developed for research (see Chapter 4) was to be used only for delivering the online tests; other features, such as discussion forum, were not used because these teachers had their own online teaching materials on their school server.

### 6.1.2 Pilot Study

In Term One (February and March 2002), with the support of the school and the two participating teachers, I conducted a small-scale pilot study in Ms Claire's class before the main project in both classes in Term Two (May and June 2002).

I observed five lessons and invited two students to participate in the pilot study. The two students did the online pretest, tried out most of the *BioLogica* activities and then did the posttest. I analysed their online tests, their log files and I interviewed one of them. The other participant was absent on the day of the interview. Findings from the pilot study allowed me to identify some issues and pose new questions. Apart from technical information about installation and use of the *BioLogica* program on students' laptop computers, I was able to give feedback, based on the work of the two students and the interview with one of them, to the teachers in the following respects:

(1) The two students had low scores on some types of genetics reasoning: from phenotype to genotype across generations (Type IV) and process reasoning about DNA as instruction for producing proteins (Type V) (see Table 3.1).

(2) The two students found learning genetics interesting and enjoyed learning with *BioLogica* activities.

(3) Useful *BioLogica* activities, as perceived by the two students and my observations, were *Introduction*, *Meiosis*, *Monohybrid*, *Inheritance* and

*Mutations*. The first three activities were used by students in School A (see Chapter 4).

These findings thus informed me to make the main study more focused in collecting data and to further revise the specific research questions of this case study (see section 6.1.3).

### 6.1.3 Specific Research Questions

Drawing on the findings of the two previous studies and the pilot study findings in Term One, I was able to reflect on the six generic research questions (see Chapter 3) and discuss some issues with the two participating teachers in planning for the main study in Term Two. The following specific research questions 6.1 to 6.5 were framed to adapt to more focused data collection and the specific context in School C:

RQ6.1 How do the teachers integrate and implement *BioLogica* and other online multimedia into their classroom teaching and learning of genetics?

RQ6.2 What are the teachers' beliefs, referents and actions in the integration and implementation of *BioLogica*?

RQ6.3 What are the major factors affecting the students' interactions with the multiple representations?

RQ6.4 How are the students motivated by the multiple representations featured in *BioLogica* and/or other online multimedia?

RQ6.5 Do the students using laptop computers have more conceptual change than do students in School A (a non-laptop school) along the epistemological, social/affective, and ontological dimensions?

As mentioned in the methodology chapter, the research methods in this case study were mapped to the specific research questions in Table 6.1 which has a similar format of Table 3.3 in Chapter 3.

Table 6.1

*Mapping the Research Methods to Research Questions in Case Study Three*

| Research Question | Data Collection Method (V = verbal data; N = numerical data) | | | | Source (T= teacher; S=students) |
|---|---|---|---|---|---|
| | Online Tests | Interviews | Observations | Documents | |
| RQ6.1 How do the teachers integrate and implement *BioLogica* and other online multimedia into their classroom teaching and learning of genetics? | | V | V | V (teaching scheme, time-table, handouts etc.) | T |
| RQ6.2 What are the teachers' beliefs, referents and actions in the integration and implementation of *BioLogica*? | | V | V | V (teaching scheme, time-table, handouts etc.) | T |
| RQ6.3 What are the major factors affecting students' interactions with the multiple representations? | V | V | V | N, V (log files) | S, T |
| RQ6.4 How are the students motivated by the multiple representations featured in *BioLogica* and/or other online multimedia? | V | V | V | | S, T |
| RQ6.5 Do the students using laptop computers have more conceptual change than do students in School A (a non-laptop school) along the epistemological, social/affect, and ontological dimensions? | N,V | V | V | N, V (test marks, assignment/ test scripts, log files) | S |

These research questions guided the data collection during the main study in Term Two and the subsequent data analyses and interpretations. The findings in terms of assertions were generated in response to these research questions.

### 6.1.4 School Context

School C is an independent or private school for girls in a middle-class suburb of the metropolitan Perth area. According to a 2001 handbook of School C, the school's ethos is to maintain academic excellence in preparing girls for the changing needs of society and encouraging them to become independent learners of tomorrow's world. In particular, the school highlights the need of their students to become confident and wise users of information and communication technologies (ICT) including computers and multimedia.

The two participating science teachers, Ms Claire and Mrs Dawson, each had over 20 years of teaching experience and several years of using the laptop computers in their teaching in the school. The participating Year 10 students ($n$ = 48) students in School C each owned a laptop computer which they bring to the classroom for use in all lessons. The wireless networking provided within the school campus makes the laptop computer a powerful machine in terms of portability and connectivity. Most of the students had English as their first language and their age was either 14 or 15 years when the research was conducted.

The private school setting allows teachers in School C more freedom in developing curriculum of their own. At the time of the research, the school had used, for a few years, a new curriculum in Year 10 biology that included DNA technology and genetic engineering taught for about one third of the teaching time in Term Two (i.e., three of the nine weeks in 2002) (see Appendix 3, Document A3.6.1). As the two teachers had been using some online materials, including some multimedia on human and molecular genetics for some years, they used both the *BioLogica* activities and the other online multimedia in classroom learning and teaching during the study. As well, the students worked on teacher-prepared worksheets, solved textbook problems, and did some experiments. The teachers used verbal/textual, visual-graphical and actional-operational representations (Lemke, 1998b) (see Chapter 2) as part of their normal teaching repertoires. The DNA extraction experiment, which was unique to School C, epitomised the new way of learning about genetics in Year 10 in Western Australian schools and reflected the beliefs and expectations of Ms Claire and Mrs Dawson in their teaching that matches the school ethos of maintaining academic excellence and nurturing independent learners.

### 6.1.5 Data Collection, Analysis and Interpretation

In May and June 2002, I conducted the main case study in Ms Claire's and Mrs Dawson's classes on a scale similar to that in School A, collecting rich data from multiple sources. To engage in the field with the participants persistently in order to better understand the case, I visited the school almost every day over eight weeks from May to July 2002 (see Figure 6.1).

As in the previous case studies, student participation was voluntary. Given the project being a collaboration between the researcher and the teachers, most students took part in the research. Twenty-four of 25 students in Claire's class (Class 1) and 21 of 23 students in Mrs Dawson's class (Class 2) took either the online pretest or posttest but only 31 students (14 in Ms Claire's class and 17 in Mrs Dawson's class) did both online tests.

Based on the pretest scores, I invited eight students, four from each class, to the interviews and an additional interviewee in Class 2 was later introduced to me by Mrs Dawson. Of these nine students, four (two from each class) were considered as having high prior knowledge in genetics reasoning or belonging to a high prior knowledge group and another five (two from Ms Claire's and three from Mrs Dawson's class) who had lower pretest scores belonged to a low prior knowledge group. These nine target students were interviewed once to three times.

Students in both classes worked on a group project about human genetic disorders based on the information on *Your Genes, Your Health* website (Cold Spring Harbour Laboratory, 2002)[25] and made their presentations in class. Therefore, I invited the target student's partner(s) in their group project to the postinstructional interview to talk about their experiences. As such, I interviewed sixteen students from two classes (seven from Ms Claire's class and nine from Mrs Dawson's) after instruction.

[25] The website of Dolan DNA Learning Center, Cold Spring Harbor Laboratory with URL at http://www.yourgenesyourhealth.org/ygyh/mason/index

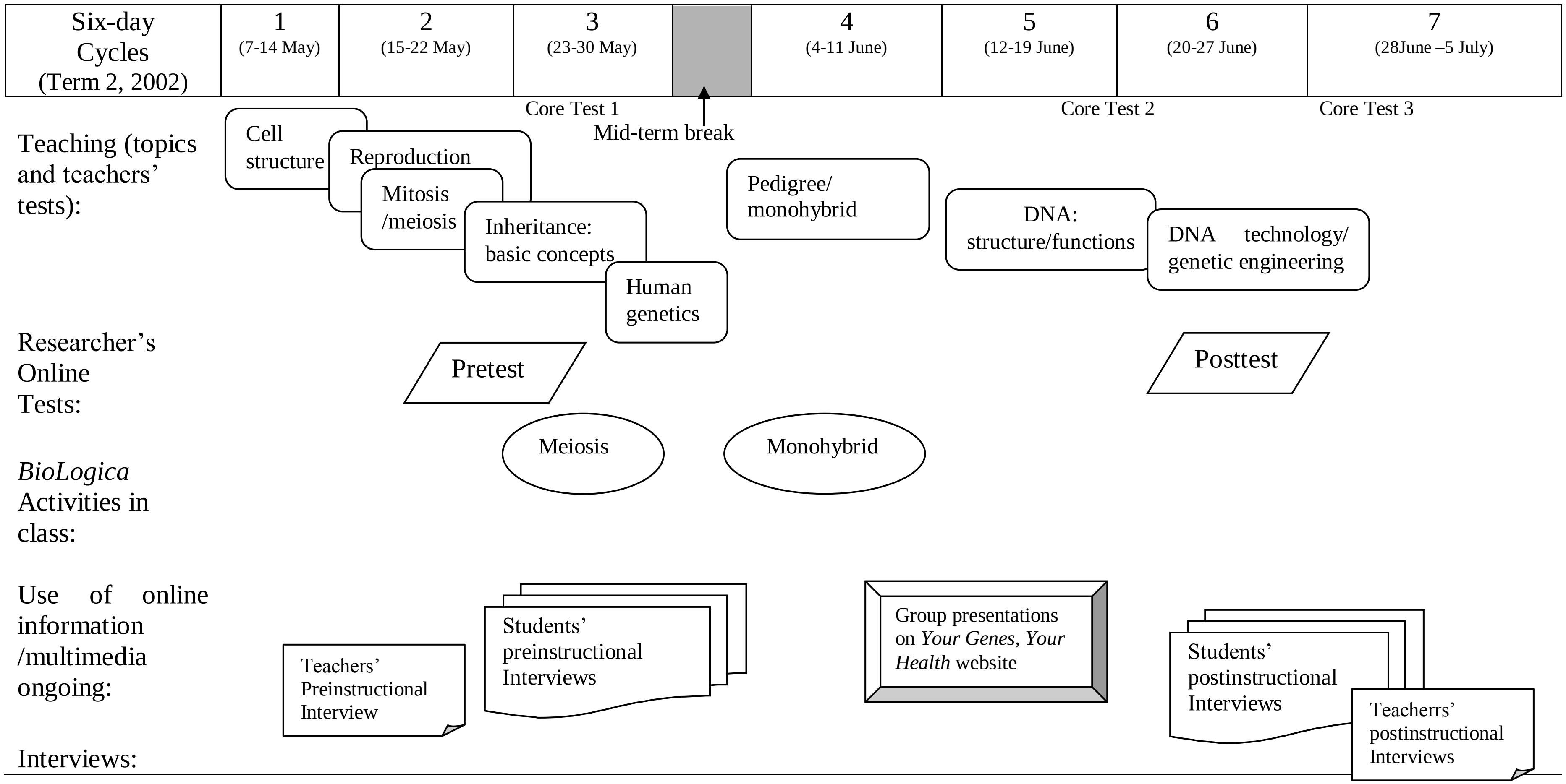



*Figure 6.1* Chronologically-ordered matrix of events of teaching and research in Classes 1 and 2 in School C. (Teaching progress and usage of *BioLogica* and other online multimedia were very similar in the two classes.)

The student interviewees' log files were collected and their notes on group presentations photocopied. However, because of minimising intrusion into normal classroom life and respecting the teacher and students' wishes, I was unable to collect the log files of non-interviewees and made copies of the students' scripts in the teachers' three tests.

As none of the lessons in the two classes was concurrent, I was able to observe most of Ms Claire and Mrs Dawson's lessons over seven weeks from 20 May 2002 to the end of the Term Two (see Appendix 1, Table A1.6.1 and Table A1.6.2). I observed 21 of Ms Claire's 23 lessons (91%) and 18 of Mrs Dawson's 24 lessons (75%). These lessons did not include three lessons when students did the teachers' written tests. Of these lessons observed, two lessons in each class were audiotaped and the classroom discourse fully transcribed for analysis. The decision to analyse these two lessons (respectively about meiosis and monohybrid cross) was made on the basis that these two topics are the most important for genetics reasoning. In another lesson of Ms Claire in which the DNA experiment was conducted, both the dialogic interactions of the teacher with the students and those between the two students, Andrea and Nancy, were audiotaped and fully transcribed for analysis.

As the research progressed, I continued my ongoing literature review, and had more conversations with my peers and experts while collecting, generating, analysing and interpreting the data. This interactive ways of going back and forth between the field, literature and conversations added rigour and richness to the ongoing analysis and interpretation of data (Huff, 1999; Merriam, 1998).

## 6.2 Teachers' Beliefs, Referents and Actions

Before teaching began, both teachers had rather high expectations of the pedagogical use of *BioLogica* but they believed that their students had different learning styles so the computer program might help some students more than others.

Ms Claire said in the preinstructional interview, "Hopefully, it will. I mean I haven't worked through the program yet but hopefully it will help them to see where it's all coming from. I meant that's the idea of using it." She then talked about the different learning styles of students.

And again it will help some more than others. I mean some of the girls don't like using computers, and there's others that do like doing games and then they ... probably would enjoy it, though we have to remember that we've all got different learning styles as well. And as I say, that's why we try to provide a range, and encourage the students that perhaps are at their main learning style as well as to develop different thinking skills. (Ms Claire/Preinstructional Interview/13 May 2002)

In the preinstructional interview, Mrs Dawson, too, talked about different learning styles of her students:

Oh, I think, um, all sorts of students have different styles of learning, different intelligences. I've had an experience of that in the last few days, where I asked the students to make me a cell, and most of them did it with boxes and plastic bags, and golf balls and whatever, but one student produced, a really amazing thing on her laptop on which she odeled her cell, and it's obviously for her that was the right thing, and I would predict that that particular student would probably get more out of *BioLogica* than some other students, because she obviously finds it the way to learn. But I guess if it's just that we're encouraged to use different styles of teaching, because different students have different learning, um intelligences. (Mrs Dawson/Preinstructional Interview/15 May 2002)

Classroom observations indicated that both teachers believed in different learning styles of students and used Gardner's (1993) multiple intelligences as a referent for their decision to use *BioLogica* as one resource to provide different opportunities for learning genetics. Instead of considering one unitary intelligence, Gardner made a case for seven intelligences: *linguistic*, *musical*, *logical-mathematical*, *spatial*, *bodily-kinesthetic*, *interpersonal* and *interpersonal.*

The following assertion was generated in response to Research Questions 6.1 and 6.2.

*Assertion 6.1*

*Both teachers held a belief that to the extent of providing opportunities to accommodate the diversity of learning styles of students, the BioLogica program is but one example of such new opportunity, therefore they did not intend to use the program more often than other resources; their referent for their action was probably Gardner's (1993) multiple intelligences.*

## 6.3 Learning with MERs in *BioLogica*

Classroom observations indicated that students did not use the *BioLogica* activities as often as the teacher required them to do. Both teachers only engaged the whole class in two *BioLogica* activities *Meiosis* and *Monohybrid* but encouraged students from time to time to use other activities on their own. The teachers scaffolded the students' learning when they worked through the two activities in class.

### 6.3.1 Usage of *BioLogica* activities

To find out the actual usage of the *BioLogica* activities, one open-ended questionnaire item was added in the online posttest. The question asked the students whether they had used any of the *BioLogica* activities given in a list or others to be named by them (see Figure 6.2).

---

Question 24

```
Which of the following BioLogica activities have you done so far?
(Please write down the numbers only.)

1.Introduction
2.Meiosis
3.Horn Dilemma
4.Monohybrid
5.Mutation
6.Mutation Inheritance
7.Others (Please name them.)
```

---

*Figure 6.2* Online self-report item about usage of *BioLogica* activities in School C.

The results of students' responses to this open-ended questionnaire item in the posttest are tabulated in Table 6.2 which indicates that not all students used the *BioLogica* activities. As only a small number of log files of students in School C were available, the data from their self-reports in the online posttest showed their usage of *BioLogica*. Classroom observations and anecdotal evidence suggested that in each class, there were always several girls whose laptop computers did not work and were unable to run the *BioLogica* activities. Some talked about this issue in the postinstructional interviews. Nancy, Andrea's peer, said "Oh. Um. I just found that it [*BioLogica*] ran very slowly on my computer. That's all that really bugged me."

Furthermore, as the MERs of genetics in the classroom learning also came from online multimedia on websites, such as *Your Genes, Your Health* (Cold Spring Harbour Laboratory, 2002) and the DNA Workshop websites (WGBH, 2002) [26], the MERs of *BioLogica* could only contribute a small part to their learning of genetics. Both Ms Claire and Mrs Dawson used a variety of representations including the use of overhead/data projector, video, physical models, data tables, simulation games/role playing, physical manipulatives, experiments, and group presentations. As such, the contribution of the *BioLogica* activities to their students' learning appeared to be less significant than expected.

Table 6.2

*Students' Self-reported Usage of BioLogica Activities in School C*

| | Students who Used *BioLogica* Activities | | | | |
|---|---|---|---|---|---|
| | Class 1 (*n* = 17) | | Class 2 (*n* = 20) | | Overall (*n* = 37) |
| *BioLogica* Activities | Number | % | Number | % | % |
| *Meiosis* [a] | 11 | 64.7 | 12 | 60.0 | 62.2 |
| *Introduction* | 10 | 58.8 | 12 | 60.0 | 59.5 |
| *Monohybrid* [b] | 9 | 52.9 | 10 | 50.0 | 51.4 |
| *Horn Dilemma* | 5 | 29.4 | 7 | 35.0 | 32.4 |
| *Mutations* | 5 | 29.4 | 3 | 15.0 | 21.6 |
| *Mutation Inheritance* | 4 | 23.5 | 4 | 20.0 | 21.6 |
| *Inheritance* | 0 | - | 2 | 10.0 | 5.4 |
| *Rules* | 0 | - | 1 | 5.0 | 2.7 |

[a] Used by students in both classes in classroom learning on 24 and 27 June 2002 (see Tables A1.6.1 and A1.6.2 in Appendix 1)

[b] Used students in both classes in classroom learning on 5 and 6 June 2002 (see Tables A1.6.1 and A1.6.2 in Appendix 1)

### 6.3.2 Scaffolding for Students Using *BioLogica*

During the two lessons (see Figure 6.1) when students were engaged in the *BioLogica* activities *Meiosis* and *Monohybrid*, both teachers scaffolded their learning through dialogues. The following two episodes, from Ms Claire's classroom on 5 June 2002, illustrate how Ms Claire scaffolded student learning by explaining

[26] http://www.pbs.org/wgbh/aso/tryit/dna/index.html

genetics using the Dragons. The dialogues were captured by two of the three tape-recorders placed in the different locations in the classroom.

When the lesson started, Ms Claire used a data projector to demonstrate a practice session in the activity *Monohybrid* and had some whole class discussion with the girls for about 15 minutes before they started to work on the *BioLogica* activity *Monohybrid*.

#### *6.3.2.1 First Episode: Plain Tail or Fancy Tail*

About 30 minutes into the lesson, Ms Claire was scaffolding the learning of a group of three students who were attempting to complete the task in Challenge 1 (see Appendix 1, Table A1.4.2)—making a plain-tailed or fancy tailed baby Dragon by breeding two parent Dragons[27]. Ms Claire had the following dialogue with a group of girls:

Ms Claire: Okay. Girls. Okay, now it won't be long before we move on a bit. Um. Have we managed to work out wings and legs?

Students: Yes. [Chorus]

Student 1: What does that do? Why have you …? [Inaudible]

Ms Claire: And you're learning about dominant [fancy] tails.

Student 2: Dominant's good.

Ms Claire: What about tails?

Student 3: Little t.

Ms Claire: Can I get a plain tail?

Student 3: Tail's the big T.

Student 1: It's two big …

Ms Claire: Big T big T,

Student 3: Big T big T.

Ms Claire: It is a fancy tail. While little t … two little ts, I've got just a plain tail without that fancy bit.

In this episode, Ms Claire was engaged in a dialogue with the three girls talking about dominance and recessiveness without using the jargon. It appeared that she

[27] The *BioLogica* program controls the flow of a student's activities in response to her actions (see Chapter 2, section 2.3.10.1). If she has previously created a plain-tailed Dragon, she is then asked to create a fancy-tailed and vice versa.

was trying to use the familiar relationship between big *T* or small *t* and the shape of the Dragon's tail to constrain the girls' interpretation of an unfamiliar representations of dominance and recessiveness in the genotype-phenotype relationship—Types I and III reasoning (see Table 3.1)

#### *6.3.2.2 Second Episode: "Betty, you killed the baby Dragon !"*

The next episode is about another group of girls—Betty and Lisa who were also attempting to complete the task in Challenge 1 (see Appendix 1, Table A1.4.2). Like the group in the preceding episode, they were making a plain-tailed or fancy tailed baby Dragon by breeding two parent Dragons. The episode began when Betty killed a baby Dragon (a male Dragon with a lethal *b* gene on its only X chromosome).

This discrepant event of a dead Dragon might have motivated the whole group.

> Lisa: Betty, you killed the baby Dragon. And make one of those things, um, little b?
>
> Ms Claire: Did any of you find anything funny happening with the X chromosome? What did you find Lisa, with the X chromosome?
>
> Lisa: Oh, if you have little b, it dies.
>
> Ms Claire: Do you give it little b? [Talking to Betty] It dies. Poor Dragon.
>
> Lisa: How come the dragon dies?
>
> Ms Claire: That must be something on that little b gene that doesn't let the Dragon develop during the embryo, something lethal,…something bad affects the development of the Dragon and it just won't grow. Class, girls, another thing to notice, we've not said much about X and Y chromosomes, and obviously chromosome pair one and two, they're homologous pairs of chromosomes, they're pairs, the X and Y we can't say their homologous, because they're different. We only get… that [male] Dragon just gets genes on the X chromosome, it doesn't have another chromosome, with an alternative, so, we've only got the dominant or the recessive characteristic, then, there's nothing to give it another combination.

As students were grappling with the genotype-phenotype relationship and the dominant or recessive state of a gene to create with plain-tailed or fancy-tailed baby Dragon, they encountered by surprise a dead male Dragon. In the light of Ogborn et al.'s (1996) framework, Ms Claire made use of the discrepant event in this episode as a resource to explain to the whole class the concepts of *lethal gene* and *sex-linkage* contextualised in the *BioLogica* Dragons.

According to Ogborn et al., Ms Claire first created two new entities in her explanation—that the little b gene "affects the Dragon's development" and that the Dragon "just won't grow"—which are not given in *BioLogica*. She then "improvised a deeper explanation" (p. 106) about sex-linked inheritance by explaining why a male Dragon dies because it "doesn't have another [X] chromosome." The two girls and the teacher were talking by referring to the entities within the context of *BioLogica* activities *Monohybrid* on one or more laptop screens. However, I was unable to collect their log files to collate the students' interactions with the MERs and the dialogue as I did in the fourth case study in School D (see Chapter 7). Therefore, I was unable to better understand how the teachers scaffolded their learning with MERs. In response to Research Question 6.1, I generated the following assertion.

*Assertion 6.2*

*Although the students had unlimited access to their own laptop computers, their usage of the BioLogica activities was lower than expected as they also used other online multimedia on molecular and human genetics; Ms Claire scaffolded student learning using the BioLogica Dragons as explanatory resources.*

## 6.4 Conceptual Learning Outcomes

### 6.4.1 Students' Perceptions of their Experiences Using *BioLogica*

Online open-ended questionnaire and interview data indicated that School C students, like those in School A, found *BioLogica* activities intrinsically motivating because of their personal interest and situational interest. As shown in Table 6.3, those activities included some of the salient features of *BioLogica* (visualisation, instant feedback and flexibility) (see Chapter 4).

Analysis of the data from online tests and interviews showed that School C students had perceptions about using *BioLogica* similar to those of the students in School A but these were less positive. Unlike students of School A who said they all liked the Dragons, some girls in School C said that preferred the websites about human and molecular genetics to the *BioLogica* activities that feature Dragon genetics. Some of them did not like using computers at all. The teachers knew about this. Early on Ms Claire told me in an e-mail message on 12 June 2002 when I was absent on two consecutive lessons.

> It was interesting today that a few of the girls asked if we had finished with *BioLogica* (perhaps you hadn't been in the last two lessons) and indicated that they didn't really enjoy using it and preferred the real life scenarios they were studying. (Ms Claire's e-mail message on 12 June 2002)

In the postinstructional interview, Ms Claire talked about how the girls preferred using the websites about human genetics than using the *BioLogica* activities.

> I think it [*BioLogica*] was just another avenue that they could see, and get another visual representation of it. I don't think, if they hadn't used *BioLogica*, that it's made any of them know any more or any less. I think it's just been another resource that has helped some of them in their learning. And that's instant feedback changing the Dragons. But, a lot of them have said to me that they, you know they, they prefer the real life stuff, and they see that [*BioLogica* activities] as sort of games and pretend, and they like, you know, prefer the real life genetics. (Ms Claire/Postinstructional Interview/4 July 2002)

Mrs Dawson also commented on her students' perceptions about learning with the computer Dragons:

> Yeah, I would say that think you'd probably have problems if you made the whole class do it. I think some girls of this age might find Dragons not quite their thing. They think they're a bit sophisticated. Um, Dragons is kind of a kid's thing…. And I did notice that there were quite a few of them that were really more interested when we were doing [about] the human conditions, the human diseases, that they found that somehow they related to that more. Other students enjoyed the things like Dragons. It just really depends on the individual student. (Mrs Dawson/Postinstructional Interview/4 July 2002)

Table 6.3

*School C Students' Perceptions about their Experiences Using BioLogica*

| Category | | Number of Students (%) Class 1 (*n* = 17) | Class 2 (*n* = 20) | Total (*n* = 37) | Sample Quotes |
|---|---|---|---|---|---|
| Those with positive comments about using *BioLogica* or find it easy to learn | | 10(59) | 12 (60) | 22 (59) | "It is fun and you get to do experiment so I find it very easy."(Rita/Class 2/Posttest) |
| Intrinsic motivation themes identified | Curiosity | 7(41) | 8(40) | 15 (41) | "It was fun and interesting and I like the Dragons." (Sandra/Class 1/Posttest) |
| | Control | 1(5) | 2(10) | 3(8) | "*BioLogica* teaches us about genetics in a way that is easy to understand and where you can learn at your own pace." (Andrea/Class 1/Posttest) |
| | Challenge | 0 | 0 | 0 | Nil |
| | Fantasy | 0 | 0 | 0 | Nil |
| | Peer support | 0 | 0 | 0 | Nil |
| Those with mixed comments about using *BioLogica* | | 2(12) | 3(10) | 5 (14) | "I find it a bit easier to understand when using *BioLogica*, yet I didn't really like the Dragons and it didn't explain itself that well and I took a while for me to figure (it) out" (Naomi/Class 2/Posttest) |
| Those with negative comments about using *BioLogica* | | 1(6) | 3(30) | 4(11) | "I think they are hard to understand on *BioLogica*." (Rose/Class 2/Posttest) |
| Those who did not answer or said "Don't know" | | 4 (24) | 2(10) | 6 (16) | "don't know" (Mimi/Class 2/Posttest) |

As to whether students appreciated the interactivity of *BioLogica* activities, Mrs Dawson said," I think what they like——and it doesn't apply to anything you might give them—is immediate feedback to know whether they're right or wrong immediately."

The website *Your Genes, Your Health* (Cold Spring Harbour Laboratory, 2002) provides online information and some multimedia that feature rich multiple representations of human and molecular genetics. There are video-clips showing the research work of scientists, medical experts explaining the genetic disorder, and people talking about their experiences of the condition. According to their online responses, most students found the multimedia on the website intrinsically motivating and none of the 37 respondents had any negative perception about the website (see Table 6.4). However, a few students like Anita complained about the poor sound effect in some multimedia.

Table 6.4

*School C Students' Perceptions about their Experiences Using the Website Your Genes, Your Health*

| Category | | Number of Students (%) Class 1 (*n* =17) | Class 2 (*n* = 20) | Total (*n* = 37) | Sample Quotes |
|---|---|---|---|---|---|
| Those with only positive comments about using *Your Genes, Your Health.* | | 12 (71) | 16(80) | 28(77) | "This is the best thing about biology. It was very interesting finding about different diseases. The text was very detailed and useful." (Alison/Class 2/Posttest) |
| Intrinsic motivation themes identified | Curiosity | 5(29) | 11(60) | 16(43) | "I found it really interesting, and having pictures and video clips to explain it to me better helped a lot." (Naomi/Class 2/Posttest) |
| | Control | 0 | 1(5) | 1(3) | "It was also very useful due to the fact you had help in your hand whenever you needed it and there was a lot of information in your hand when you needed it most." (Elaine/Class 2/ Posttest) |
| | Challenge | 0 | 0 | 0 | Nil |
| | Fantasy | 0 | 0 | 0 | Nil |
| | Peer support | 1(6) | 1(5) | 2(5) | Nil |
| Those with mixed comments about using *Your Genes, Your Health* | | 2(12) | 4(20) | 6(16) | "I thought it was good but it's hard to listen to the video in the classroom. Sometimes the pop-ups didn't work that well."(Anita/Class 2/Posttest) |
| Those with only negative comments about using *Your Genes, Your Health* | | 0 | 0 | 0 | Nil |
| Those who did not answer or said "Don't know. | | 3(18) | 0 | 3(8) | Nil |

As will be discussed in the following sections, although School C students had similar improvement in genetics reasoning compared to School A students, multiple sources of data indicated that a few high-achievers such as Andrea (see section 6.4.3.3) displayed sophisticated gene conceptions not observed in School A, even for high-achievers such as Matthew (see Chapter 4). Such differences of their learning along the ontological dimension were likely due to School C students' engagement in

*BioLogica* activities *Mutations* and *Mutation Inheritance* as well as online multimedia on human and molecular genetics, of which School A students had no such experiences.

A comparison was made between the students' comments on their experiences using *BioLogica* and other multimedia exemplified by those on the website *Your Genes, Your Health* (see Figure 6.3). The 37 respondents had slightly more positive perceptions in favour of the website *Your Genes, Your Health*.

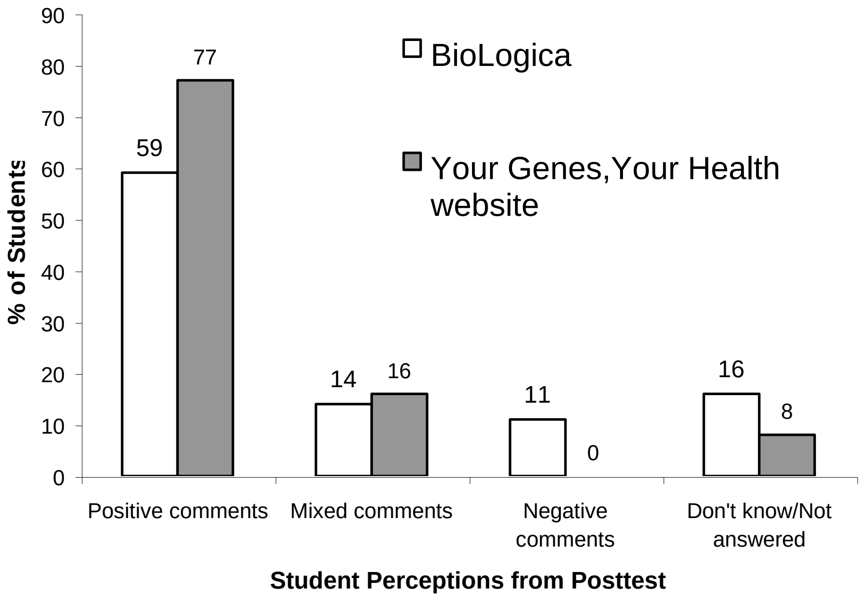



*Figure 6.3* Comparison of student perceptions of *BioLogica* program and *Your Genes, Your Health* website.

On the basis of the preceding analyses and interpretations, I generated Assertion 6.3 in response to Research Question 6.4 to summarise the finding.

Assertion 6.3

*Although most students were highly motivated and enjoyed learning genetics with online information and multimedia on their laptop computers, many preferred some web-based multimedia on human and molecular genetics to BioLogica activities. Subsequently, the students did not use BioLogica activities as often as expected.*

## 6.4.2 Genetics Reasoning

### *6.4.2.1 Improvement Across Reasoning Types and Classes*

The major focus of the online tests was on genetics reasoning of six types (see Table 3.1). As Figure 6.4 shows, online pretest results indicated that the prior knowledge of Mrs Dawson's class (Class 2) about genetics reasoning was lower than that of the students in Ms Claire's class (Class 1). As I observed most of the lessons in both classes, the material covered by the teacher and the *BioLogica* activities and other online multimedia in which the students were engaged were the same. Classroom observations indicated that students in Class 2 were generally less attentive and had lower engagement on tasks. Their teacher Mrs Dawson told me before instruction in our informal conversations that the students in her class (Class 2) were not so interested in learning genetics. Posttest results showed that the mean scores of Class 2 were lower on most types of genetics reasoning (see Figure 6.4).

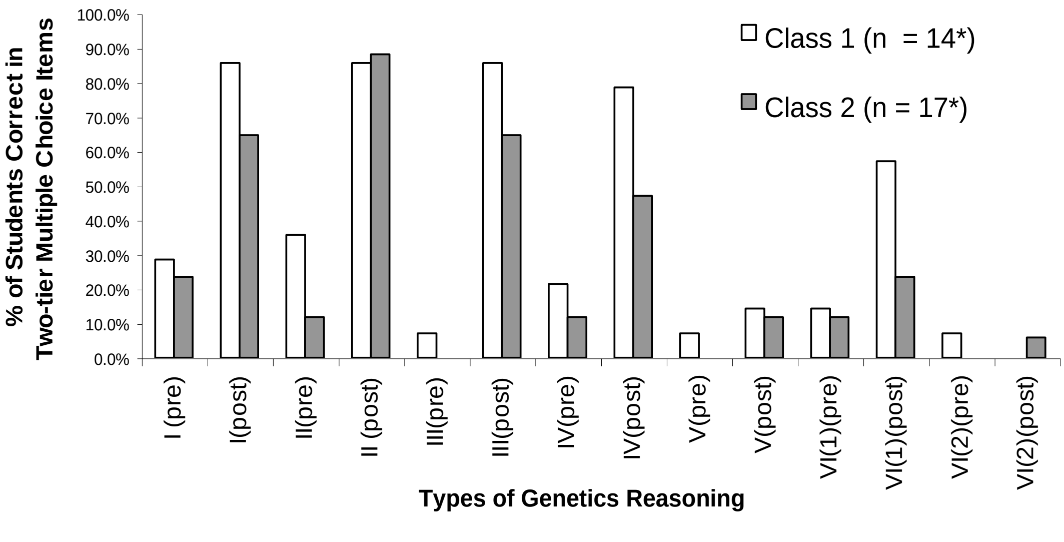



*Figure 6.4* Comparison of genetics reasoning of students in Classes 1 and 2 in School C.

### *6.4.2.2 Genetics Reasoning: Comparison of School C and School A*

When the online test results of School C were compared to those in School A, the mean scores of the six common two-tier items indicated that students' improvement in genetics reasoning across the two schools followed a similar pattern (see Figure

6.5). Students in School C did not outperform those in School A in genetics reasoning despite the former had unlimited access to *BioLogica* and other online multimedia using the student-owned laptop computers. As Figure 6.5 shows, School A results were slightly better than School C in three of the four Types of genetics reasoning and in the posttest mean score.

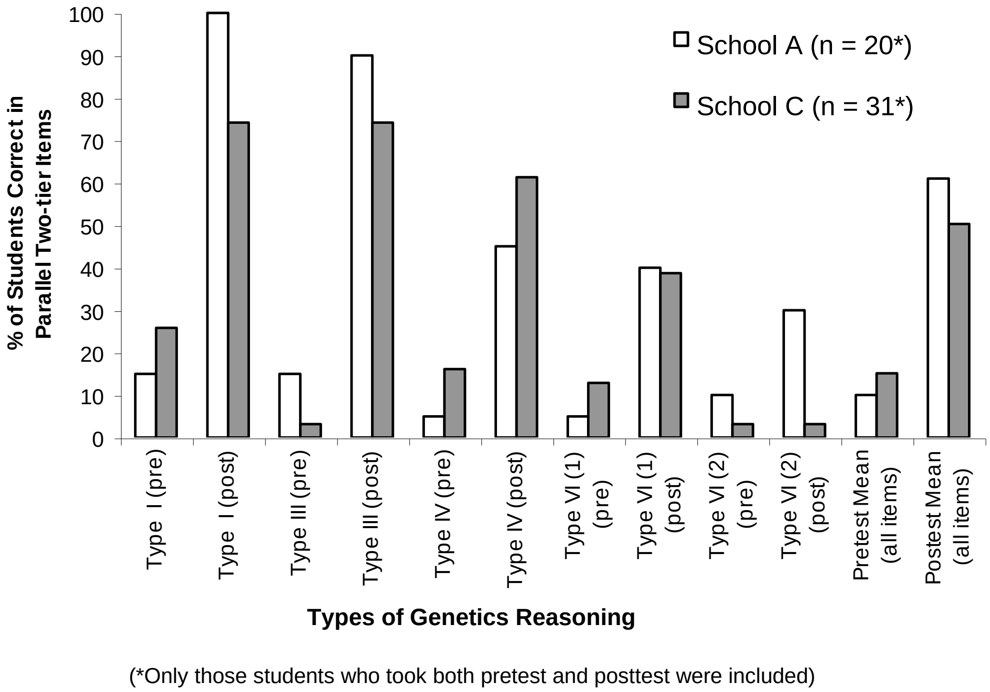



*Figure 6.5* Comparison of genetics reasoning of students in Schools A and C.

In response to Researsch Question 6.5, I generated the Assertion 6.4 to summarise the finding.

*Assertion 6.4*

*Most students improved their genetics reasoning but only in easier types in a pattern similar to the results in School A despite School C students having unlimited access to their laptop computers.*

#### *6.4.2.3 Genetics Reasoning: Comparison of Two Groups of Interviewees*

The nine student interviewees (four from Class 1 and five from Class 2) were purposefully selected for the interview primarily based on their scores in the online pretest about genetics reasoning. According to the pretest scores, they were categorised as a low or high prior knowledge group. After instruction, the posttest results indicated that both groups improved their genetics reasoning although the increase was greater in the high prior knowledge groups (see Table 6.5).

Table 6.5

*Pretest-posttest Comparison of Genetics Reasoning in Interviewees of School C*

| Group | Name /Class | Responses to Six Types of Genetics Reasoning Test Items[a] | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | | II | | III | | IV | | V | | VI(1) | | VI(2) | | Score (%) | |
| | | pr [d] | ps [e] | pr | ps | pr | ps | pr | ps | pr | ps | pr | ps | pr | ps | pr | ps |
| LA[b] | Cindy/1 | ■ | ■ | | ■ | | ■ | | | | | | ■ | | | 14.3 | 57.1 |
| | Erika/1 | | ■ | | ■ | | ■ | | ■ | | | | | | | 0 | 57.1 |
| | Rita/2 | | ■ | | ■ | | | | | | | | | | | 0 | 28.6 |
| | Terri/2 | | | | ■ | | ■ | | ■ | | | | ■ | | | 0 | 57.1 |
| | Etta/2 [c] | | | | ■ | | | | | | | | | | | 0 | 14.3 |
| HA[c] | Andrea/1 | | ■ | | ■ | | ■ | ■ | ■ | | ■ | ■ | ■ | | | 28.6 | 85.7 |
| | Isabelle/1 | ■ | ■ | ■ | ■ | | ■ | | | | ■ | | ■ | | | 28.6 | 71.4 |
| | Elaine/2 | ■ | ■ | | ■ | | ■ | ■ | ■ | | | | | | | 28.6 | 57.1 |
| | Anne/2 | ■ | ■ | ■ | ■ | | ■ | | ■ | | | | | | | 28.6 | 57.1 |

[a] A shaded cell in the table denotes a correct answer for a two-tier item in the online tests

[b] LA =Low prior knowledge group; [c] HA = High prior knowledge group [d] pr=pretest; [e] ps = posttest.

The second pattern of the student improvement is that the interviewees in Ms Claire's class had made more improvement than those in Mrs Dawson's class. Terri of Mrs Dawson's class was an exception (see Figures 6.6 and 6.7).

Furthermore, analysis of the postinstructional interview transcripts revealed that those low prior knowledge students (pretest score of 0%) who had made substantial pretest-posttest gains held more positive perceptions than did those whose gains were smaller. For instance, two low prior knowledge students from Class 2 talked about their experiences in the postinstructional interview/online tests. Terri, whose pretest-posttest gain was +57.1%, said in her posting, "it [*BioLogica*] helped me understand them a lot better." In her interview, Terri talked about her experiences using *BioLogica*, "Oh the *BioLogica*. Um, yeah. Yeah. The Dragons were cool. A bit, yeah. It was good."


*Figure 6.6* Comparison of improvement in genetics reasoning in the high prior knowledge group across two classes.

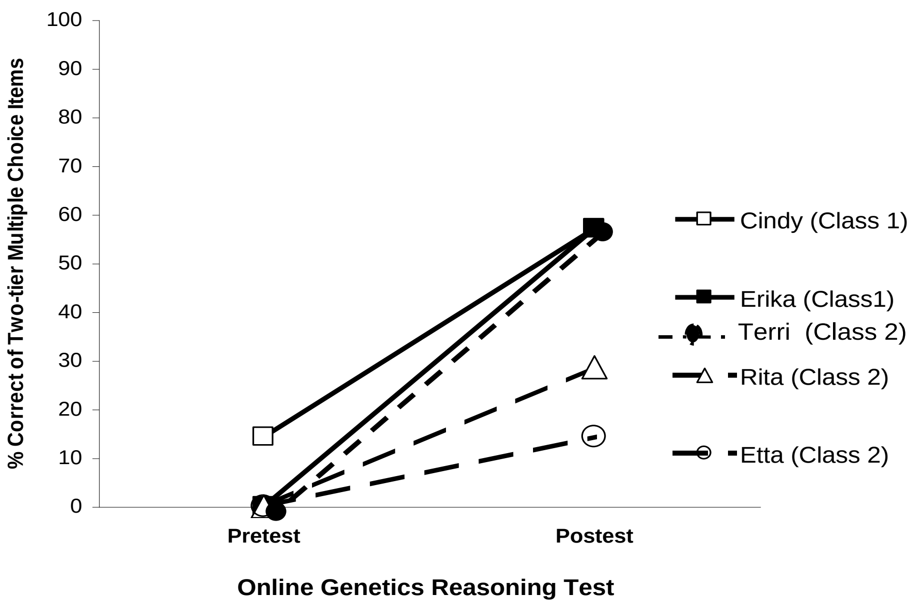



*Figure 6.7* Comparison of improvement in genetics reasoning in the low prior knowledge group across two classes.

In contrast to Terri, Etta, whose pretest-posttest gain was only +14.3%, did not wish to be interviewed again after instruction and she held negative perceptions about the *BioLogica* activities as she said in her posting, “I tried a few, *Introduction, Meiosis, Monohybrid, Mutations* and *Mutation Inheritance* but I never finished any. The program was just too confusing, hard to run and immature.” Of all the 16 interviewees, Etta was one of the two girls who held negative perceptions about *BioLogica*.

In response to Research Question 6.3, I generated Assertion 6.5.

*Assertion 6.5*

*Low prior knowledge students who did not make substantial improvement in genetics reasoning appeared to have less interest, motivation and engagement in BioLogica activities.*

### 6.4.3 Gene Conceptions

#### ***6.4.3.1 Preinstructional-postinstructional Change in Class-wide Gene Conceptions***

As for the gene conceptions, there were also class-wide differences in terms of sophistication (Venville & Treagust, 1998) before and after instruction (see Figure 6.8).

The first major change in the conceptions about the gene included a decrease in the number of students holding the conceptions of a gene being something passed from their parents or grandparents and a sharp increase of those who conceptualised the gene as part of a chromosome. Second, a very high percentage of School C students held the conception about a gene being a part of the DNA and this increased slightly after instruction (see Figure 6.8). Classroom observations indicated that these results matched the way the two teachers taught the part about the cell structure and function (before the instruction about genetics) that included the DNA in the nucleus. However, it was surprising that none of the students in the two classes mentioned in the pretest that genes are on the chromosomes. As Figure 6.8 shows, in the posttest, 53% in Class 1 and 35% in Class 2 mentioned this conception. The chromosomes were mentioned in the part about cell structure and function. What might have contributed to this change were probably their experiences using *BioLogica* and the multimedia in the website *Your Genes, Your Health* that feature rich linked MERs displaying the gene-on-chromosomes model that helped understanding. Both teachers required their students to work on a group project based on the multimedia on this website and present it in class. Classroom observations indicated that most students were interested in the project presentation.

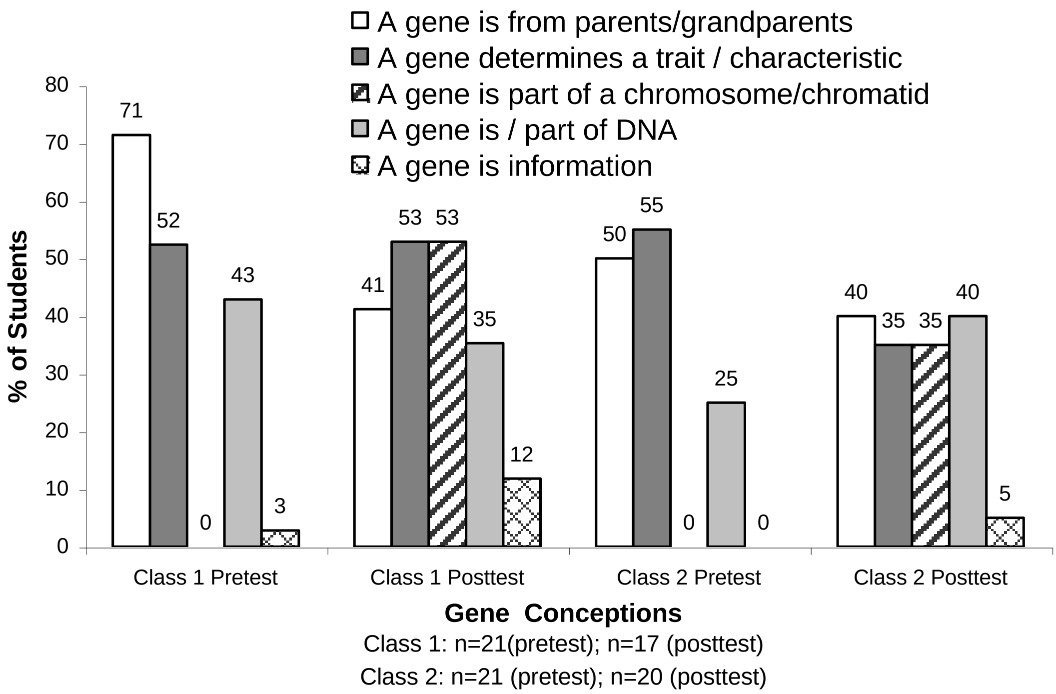



*Figure 6.8* Comparison of pretest-posttest change in students' gene conceptions across two classes in School C.

#### *6.4.3.2 Ontological Progression of Class-wide Gene Conceptions*

As shown in Figure 6.8, the change in School C students' gene conceptions being information (Venville & Treagust, 1998) was similarly low (less than 10%) compared to students in School A (see Chapter 4). This result was consistent with the pretest-posttest increase, from 2% to 8% (not shown here), in a parallel two-tier question on Type V genetics reasoning about a gene being a process (see a sample in Figure A2.4.6 in Appendix 2). However, as the students took the posttest while DNA function and protein synthesis was being taught (see Table A1.6.2 in Appendix 1), the results of the open-ended and the two-tier questions might not fully indicate the actual ontological progression of their gene conceptions. Interviews that followed the posttest did provide more information about their ontological conceptual change—some high-achievers in both classes had rather sophisticated conceptions of genes. Inasmuch as the data indicated, these students had ontological conceptual change across the categories (Chi, 1992), an outcome not found in a previous study in School A (see Chapter 4).

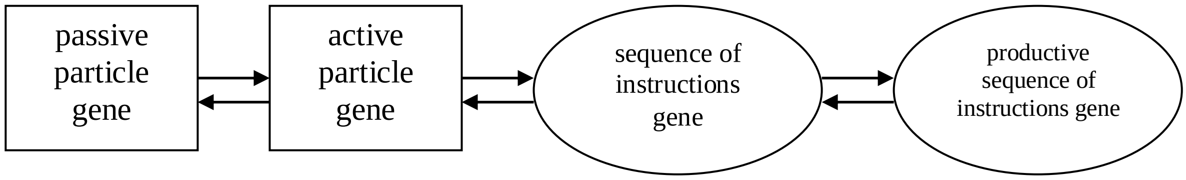
#### *6.4.3.3 Andrea's Ontological Change: A Vignette*

As I noticed in my first few classroom observations, Andrea was always very attentive in class and actively participated in classroom discussions. Her online pretest score (29%) and posttest score (86%) indicated that she was one of the high-achievers in her class. She eventually ranked the first in Ms Claire's tests with grade A and an overall average mark of 89%. Her preinstructional conception of genes was intelligible and plausible (see Figure 6.9).

I had the following dialogues with her in the preinstructional interview:

Interviewer: So what do you know about genes now?
Andrea: Um, well we've just been learning about the chromosomes and how they make up the characteristics of the physical features and stuff.
Interviewer: Mm. Thank you. So what do you think a gene does?
Andrea: A gene? Um, I think it's like, the plans for your characteristics and it tells what each cell should do and stuff.
Interviewer: How do your genes control those characteristics? Any ideas?
Andrea: Um I don't know um. I just heard that it's in the nucleus and then the nucleus passes it on to the rest of the cell and, yeah.

Like most students in other case schools, Andrea initially conceptualised the gene as a part of the chromosome that determines the physical characteristics of an individual. Before instruction, Andrea's conception of genes was both intelligible and plausible according the Venville and Treagust's (1998) interpretation (see Figure 6.9) but not fruitful as her conception was not sophisticated (see transcript lines 7-9).




Andrea's Conception Status: IP (Intelligible-Plausible) → IPF (Intelligible-Plausible-Fruitful)

*Figure 6.9* Ontological progression in Andrea's conceptions of the gene (Adapted from Venville & Treagust, 1998, p. 1049).

Then after instruction, Andrea posted the following response to the open-ended questionnaire item in the online posttest:

> A gene is made up of DNA, which contains instructions that decide a person's characteristics. There can be different kinds of genes which are called alleles. People inherit all of their genes from their parents.

After instruction, I interviewed Andrea twice to probe the change in her gene conception. On 28 June 2002, just after Ms Claire had taught about protein synthesis, I interviewed Andrea in the presence of Nancy, her peer. When asked about what a gene does, she was able to craft an explanation of DNA being information which codes for proteins (see transcript lines 11-17). .

Interviewer: What do genes do in the body?
Andrea: Oh. Um. Well genes are made up of the genetic code in the DNA, which tells the body to make proteins, and um, um they just carry the information which tells the body how it should work and stuff and how it should develop.
Interviewer: How does the information control all the development and so on?
Andrea: Um. Well each gene um, consists of genetic code which is used to produce proteins.

Then, on 2 July, after the Ms Claire had finished all the teaching of the unit, I had another short interview with Andrea and Nancy was also with us.

Interviewer: So what do genes do in the body?
Andrea: What do the genes do? Oh, they contain the genetic code that produces protein which contains amino acids that you know help us.
Interviewer: So what do you mean by protein synthesis?
Andrea: Protein synthesis. What's protein synthesis?
Interviewer: You understand?
Andrea: I don't remember.
Interviewer: Any ideas?
Andrea: No.
Nancy: It's the way (something makes a copy of something…)[not audible]
Andrea: Nancy thinks...
Interviewer: So how are proteins made from, like DNA?
Andrea: Oh, yeah, um. Nancy thinks that it's when protein um, is made from the DNA and, how, I don't know.
Interviewer: So what is messenger RNA?
Andrea: Oh well um, the messenger RNA, they copy the DNA code, from the genes, and then they transfer it to the ribosomes. Is that it?
Interviewer: So what are uses of proteins in the body?
Andrea: The uses of proteins. Oh, um, proteins, um, I don't know um, well they help to repair cells and um, I don't know.
Interviewer: So thank you very much.

As can be seen in the above transcript, Andrea's gene conception is interpreted here as intelligible-plausibility-fruitful (IPF) or a productive sequence of instruction for making protein (see transcript lines 19-20, 33-34, and 36-37), which is the most sophisticated conception according to Venville and Treagust (1998) (see Figure 6.9). However, it appeared that Andrea was not confident enough when she talked about her new conception. Probably she did not have the vocabulary to verbalise her ideas. Nancy's suggestion of "copy" (line 27) and the interviewer's prompt of "messenger RNA" (line 32)—which Ms Claire mentioned in the previous lessons—might be useful explanatory resources (Ogborn et al., 1996) for Andrea in verbally explaining how DNA produces proteins. I will analyse Andrea's gene conception again in the cross-case analyses chapter (Chapter 8) using Thorley's (1990) status analysis categories.

As discussed in Chapter 2, the conception of genes as particles on a chromosome or a section of a DNA molecule, belongs to the ontological category of *matter* whereas genes being sets of productive sequence of instructions for protein synthesis (Venville & Treagust, 1998) belongs to the category *processes* (Chi et al., 1994, p. 31). As such, over the two months' learning with *BioLogica* and other online resources, Andrea's conception of the genes had undergone a radical conceptual change that involved a shift in the ontological status or conceptual change across ontological categories from matter to process (Chi, 1992).

In the first postinstructional interview, I had the following dialogue with Andrea and her peer Nancy about their experiences of making their class presentation about Huntington's disease based on the information of the website *Your Genes, Your Health*.

Nancy: I thought it was very easy to use, so that always
makes it like more enjoyable, because you don't have to go
searching for the information. Plus the presentations we
were doing were very simple, so, all the information was pretty much
"you put your mouse over it" and you could see the information you
needed.

Interviewer: Yes.

Nancy: But it was like an easy resource to use. That's what struck me.

Andrea: Yeah. And it, like, there weren't like, long, really hard language
to understand. Like, we understood everything that they said,
because they said it in like, you know-

Nancy: Any dummy could understand.

Andrea: Yeah. Any person could understand it.

Nancy who said she did not like genetics in her pretest posting appeared to have enjoyed the group presentation. She found that the information easy to retrieve and understand. Unfortunately, she did not do the posttest so that there was not enough information about how often she had been engaged in *BioLogica* activities.

The foregoing vignette points to Assertion 6.6 generated in response to Research Question 6.5. Besides Andrea's high level of engagement in *BioLogica*, her log files (see a sample in Document A3.6.1 in Appendix 3) indicated that her interactions with the MERs in *BioLogica* were mindful (see Chapter 4).

*Assertion 6.6*

*Although most students' ontological conceptual change was within the category of matter and their conceptions were only intelligible-plausible (IP), some high achievers displayed radical conceptual change across ontological categories (from matter to process) and their conceptions were intelligible-plausible-fruitful (IPF).*

## 6.5 To Complement or to Constrain

The multimedia on the *Your Genes, Your Health* website appeared to provide students with complementary information and processes more than to constrain their interpretation of situations and phenomena whereas the *BioLogica* activities were more challenging and more difficult but they appeared to support learning by way of three functions of MERs: to complement, to constrain and to construct.

The fact that some School C girls did not like the *BioLogica* Dragons caused me to rethink about the three functions of multiple representations. From the perspectives of multiple external representation (MERs) (Ainsworth, 1999), the online interactions with the websites may serve the first and third functions of MERs, i.e., to complement information of processes and thus to encourage students to construct deeper understanding of the phenomena. It appeared that such web-based materials, in particular the multimedia in the website from *Your Genes, Your Health,* intrinsically motivated the students because of the visual-graphical representations and the personal relevance of the real-life examples of human genetics.

Students enjoyed the experiences with these websites on human and molecular genetics and their group presentations but some of them did not like the *BioLogica* Dragons because they were not humans. As Etta said, "Well, I like everything apart from [the] *BioLogica* program because I found them confusing and immature in relation to the graphics of dead Dragons" (Etta/Posttest/27 June 2002). The teachers had similar ideas. Mrs Dawson said in the postinstructional interview, "Dragons is kind of a kid's thing" and Ms Claire said, "they see that [*BioLogica* activities] as sort of games and pretend, and they like, you know, prefer the real life genetics."

Nevertheless, despite these comments from students and teachers, *BioLogica* activities appeared to support student learning in School C by way of all three functions, particularly to constrain students' interpretation or misinterpretation of the phenomena of genetics. School A students' greater engagement in *BioLogica* activities compared to students in School C may be a plausible explanation for Assertion 4.5 (see section 4.4.1.3). Further, like high-achievers such as Matthew of School A, Andrea who made substantial improvement appeared to have had a higher engagement with *BioLogica* and believed that the activities were useful for understanding.

According to Ainsworth (1999), one way of constraining interpretation is to exploit a familiar representation "to support the interpretation of a less familiar or more abstract one and to provide support for a learner as they extend, or revise misconceptions in, their understanding of the unfamiliar" (p. 139). The use of analogies and metaphors in classroom teaching is similar to this idea. *BioLogica* Dragons surely provide a familiar representation (with simple genotype, just three pairs of chromosomes containing seven genes and familiar phenotype such as horns, legs and wings and skin colour) to constrain student interpretation of a second representation of much more complex human genotype (many genes in 23 pairs of chromosomes) and phenotype (eye colour, tongue-rolling, cystic fibrosis or haemophilia). As Ainsworth (1999) explained,

> The primary purpose of the constraining representation is not to provide new information but to support a learner's reasoning about the less familiar one. It is the learner's familiarity with the constraining representation, or its ease of interpretation, that is essential to its function. (p. 139)

The above explanation clearly points to the constraining function of MERs. It follows that Dragons are familiar constraining representations for interpreting human genetics. It was not until in Case Study Four (School D) that Ms Elliott appreciated the pedagogical use of *BioLogica* Dragons (see Chapter 7).

## 6.6 Summary of Findings

The findings of Case Study Three are summarised below in terms of the assertions generated in the preceding sections in response to the specific research questions (see

Table 6.6). Assertion 6.7 is an emergent theme to be explored further in Case Study Four.

Assertion 6.1

Although the students had unlimited access to their own laptop computers, their usage of the *BioLogica* activities was lower than expected as they also used other online multimedia on molecular and human genetics. Ms Claire scaffolded student learning using the *BioLogica* Dragons as explanatory resources.

Assertion 6.2

Although the students had unlimited access to their own laptop computers, their usage of the *BioLogica* activities was lower than expected as they also used other online multimedia on molecular and human genetics; Ms Claire scaffolded student learning using the *BioLogica* Dragons as explanatory resources.

Assertion 6.3

Although most students were highly motivated and enjoyed learning genetics with online information and multimedia on their laptop computers, many preferred some web-based multimedia on human and molecular genetics to *BioLogica* activities. Subsequently, the students did not use *BioLogica* activities as often as expected.

Assertion 6.4

Most students improved their genetics reasoning but only in easier types in a pattern similar to the results in School A despite School C students having unlimited access to their laptop computers.

Assertion 6.5

Low prior knowledge students who did not make substantial improvement in genetics reasoning appeared to have less interest, motivation and engagement in *BioLogica* activities.

Assertion 6.6

Although most students' ontological conceptual change was within the category of matter and their conceptions were only intelligible-plausible (IP), some high achievers displayed radical conceptual change across ontological categories (from matter to process) and their conceptions were intelligible-plausible-fruitful (IPF).

Table 6.6

*Summary of Assertions Mapped to Research Questions in Case Study Three*

| Research Question | Assertions | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 |
| RQ6.1 How do the teachers integrate and implement *BioLogica* and other online multimedia into their classroom teaching and learning of genetics? | √ | √ | | | | | |
| RQ6.2 What are the teachers' beliefs, referents and actions in the integration and implementation of *BioLogica*? | √ | | | | | | |
| RQ6.3 What are the major factors affecting students' interactions with the multiple representations? | | | √ | | √ | | |
| RQ6.4 How are the students motivated by the multiple representations featured in *BioLogica* and/or other online multimedia? | | | √ | | | | |
| RQ6.5 Do the students using laptop computers have more conceptual change than do students in School A (a non-laptop school) along the epistemological, social/affect, and ontological dimensions? | | | √ | √ | | √ | √ |

The major finding of Case Study Three is embedded in Assertions 6.4 and 6.6 in response to Research Question 6.5. Compared to School A with similar prior knowledge, School C students had similar conceptual change along the social/affective and epistemological dimensions but had more ontological conceptual change. Their teachers' actions in teaching and their unlimited access to ICT appeared to be the major factors for the difference. However, School C teachers did not fully harness the constraining representations in *BioLogica* for developing genetics reasoning. Table 6.6 maps the assertions to the respective research questions in this case study.

## 6.7 Limitations of Case Study Three

Although the findings in School C were unique in this study because of students' ownership and portability in learning with their laptops, some limitations must be considered when interpreting the findings.

First, Ms Claire and Mrs Dawson, already had a well-established curriculum for learning using the laptop computers and there were limited possibilities for integration of *BioLogica* in their teaching. I reported a similar observation in School A (Tsui & Treagust, 2003). Second, another limitation, related to the first one, is that the girls did not use *BioLogica* as often as other online resources on human and molecular genetics so that the contribution of the MERs of *BioLogica* to their learning was not significant for most students. Third, I was unable to collect enough log files for analysing the students' interactions with *BioLogica*.

## 6.8 Discussion and Conclusions

Despite the limitations discussed in the preceding section, students' learning outcomes appeared to be consistent with their prior knowledge, personal interest, motivation, the teachers' action in teaching genetics, the classroom discourse, and the kind of multimedia they used most often in their learning.

Two pedagogical aspects of using multimedia for learning genetics, based on Ainsworth's (1999) review, may need further investigation: (1) how different multimedia serve the three functions MERs which researchers claim, namely, "to complement, to constrain, and to construct" (p. 134); and (2) how teachers can scaffold students' translation between the representations "if MERs are used to develop deeper understanding" (p. 150). So far, "no research has yet examined the role of translation in learning environments in the light of these different claims."(p. 150).

In Stolarchuk and Fisher's (2001) study of 14 independent laptop schools across four Australian states, their qualitative data strongly supported the conclusion that the use of laptop computers in science did not help to increase student cognitive achievement when compared with non-laptop students. As such, it is not surprising to find that students in School C did not appear to outperform another non-laptop school in their improvement in genetics reasoning.

# Chapter 7

# Case Study Four :

# Learning Genetics with Multiple Representations in an ICT-rich Learning Environment

## 7.0 Overview

This chapter documents the last case study with a major focus on the learning of a class Year 12 Human Biology students in School D, a new state senior school which incorporates an ICT-rich learning environment with work-based learning for career or further studies. A biology teacher and her students—in one Year 12 Biology TEE class ($n$ = 6) and one Year 12 Human Biology TEE class ($n$ = 11)—participated in the study.

The biology teacher, Ms Elliott (pseudonym) integrated and implemented most of the *BioLogica* activities in her teaching by selecting, sequencing and pacing these activities to cater for the differing interests and abilities of the students in the two classes. Students learnt genetics when they regularly engaged in *BioLogica* activities. Findings suggested that the teacher's beliefs underpinned her actions in teaching with *BioLogica* and a high level of teacher-researcher collaboration made the learning environment more sensitive to student learning needs. Whereas most students improved their genetics reasoning as indicated by the online tests, some Human Biology students with low prior knowledge made substantial improvements. On reflection, the teacher and most students generally held positive perceptions about their learning experiences with *BioLogica*.

## 7.1 Methods

This case study, like the previous three case studies, basically followed an interpretive approach (Erickson, 1986, 1998; Gallagher, 1991) and a case-based design using multiple data collection methods (Merriam, 1998) as described in detail in Chapter 3.

### 7.1.1 Specific Research Questions

The findings of the previous three case studies (see Chapters 4, 5 and 6) informed me to rethink about the initial six research questions (see Chapter 3) in relation to the unique school context in School D, particularly the Year 12 Biology/Human Biology curriculum for the TEE. Based on the emergent design in case study methodology (Merriam, 1998), the specific questions for this case study are as follows:

RQ7.1 How does the teacher integrate and implement *BioLogica* in her classroom teaching and learning of genetics to support students with low prior knowledge to prepare for the Tertiary Entrance Examinations (TEE)?

RQ7.2 What are the teacher's beliefs, referents and actions in the integration and implementation of *BioLogica* in her teaching of genetics?

The first two research questions 7.2 and 7.3 remain similar to those in other case studies and draw on the previous research findings but a new focus in this case study is on how the teacher differentially used technology to support the students with low prior knowledge.

RQ7.3 To what extent does the social/affective dimension of conceptual learning affect their engagement in *BioLogica* activities?

Research question 7.3 examines the roles of motivation/social factors that affect students' engagement in *BioLogica* activities on the basis of the findings in the previous case studies. Given that the number of *BioLogica* activities used in this case study was the highest in all four case schools, regularity of engagement in the activities and interaction with the MERs was likely to depend on the social/affective dimension.

RQ7.4 What factors affect the students' development of genetics reasoning when they interact regularly with the MERs of *BioLogica*?

Research Question 7.4 explores the factors affecting students learning to reason and solve problems when they are interacting with MERs of *BioLogica*. In particular, this question examines the role of *mindfulness* which was first identified in School A in predicting the learning outcome. As discussed in Chapter 2, mindfulness is defined by Salomon and Globerson (1987) as the "volitional, metacognitively guided employment of non-automatic, usually effortful processes"(p. 623). Using the Vygotskian perspective adopted by Davidson and Sternberg (1985), this is also related to how well the students can transfer genetics reasoning that they developed (*competence*) from the computer-based multiple representations to problem solving in their tests (*performance*). Accordingly, Vygotsky's (1978) zone of proximal development can be viewed as the difference between competence and performance. As such, Research Question 7.4 also explores students' metalearning (White & Gunstone, 1989) and collaborative peer learning (Crook, 1994).

RQ7.5 How do the students learn genetics through their interactions with *BioLogica* in terms of the three functions of MERs?

Research Question 7.5 attempts to map the students' learning with *BioLogica* MERs to the three functions of MERs, namely, *to complement, to constrain* and *to construct* (Ainsworth, 1999). Multiple sources of data are analysed and interpreted to seek answers in response to the research question.

RQ7.6 Have the students undergone a three-dimensional conceptual change after the *BioLogica* experience?

Research Question 7.6 is about the students' conceptual change along three dimensions after instruction that included *BioLogica* activities as an integral part (Hewson & Lemberger, 2000; Hewson & Hewson, 1992; Posner et al., 1982; Tyson et al., 1997). The status of conceptual learning related to the Research Question 7.6 will eventually be discussed in cross-case analyses of selected students from Schools A, C and D in Chapter 8.

### 7.1.2 Mapping Research Methods to Research Questions

The research methods are mapped to the specific research questions of this case study as shown in Table 7.1.

Table 7.1

*Mapping the Research Methods to Research Questions in Case Study Four*

| Research Question | Data Collection Method (V = verbal data; N = numerical data) | | | | Source (T= teacher; S=students) |
|---|---|---|---|---|---|
| | Online Tests | Interviews | Observations | Documents | |
| RQ7.1 How does the teacher integrate and implement *BioLogica* in her classroom teaching and learning of genetics to support students with lower prior knowledge in preparing for the Tertiary Entrance Examinations (TEE)? | | V | V | V (teaching scheme, time-table, handouts etc) | T |
| RQ7.2 What are the teacher's beliefs, referents and actions in the integration and implementation of *BioLogica* in her teaching of genetics? | | V | V | V (teaching scheme, time-table, handouts etc) | T |
| RQ7.3 To what extent does the social/affective dimension of conceptual learning affect the students' engagement in *BioLogica* activities? | | V | V | | T |
| RQ7.4 What factors affect students' development of genetics reasoning when they interact regularly with the MERs of *BioLogica* ? | V | V | V | N,V (log files) | S, T |
| RQ7.5 How do the students learn genetics through their interactions with *BioLogica* in terms of the three functions of the MERs? | V | V | V | N, V | S |
| RQ7.6 Have the students undergone a three-dimensional conceptual change after the *BioLogica* experience**?** | N, V | V | | N, V (test marks, assignment/ test scripts, log files) | S |

Some new strategies were adopted to make the study more focused. For example, to examine the learning of students with low prior knowledge, purposeful sampling (Patton, 1990) (see section 3.6.2.1) sought data from information-rich cases, including audio-recording of dialogues of a selected dyad at the computer and some new foci in the questions asked in the teacher and student interviews. As students were busily preparing for the Tertiary Entrance Examinations (TEE), I decided to conduct one short student postinstructional interview with perception questions only. Whereas questions on gene conceptions were not included, the genetics reasoning tasks in the interview were modified into two-tier items for use in the online tests. As in other schools, the web-based course was only used for delivering the researcher's online tests. Furthermore, I worked in collaboration with Ms Elliott to provide feedback to the students about their online test results and their performance in the *BioLogica* activities. Data analyses and interpretations adopted some new strategies of Miles and Huberman (1994) for displaying and revealing themes and patterns. Lastly, the software tools *NUD*IST* and *NVivo* were used in coding verbal data and indexing and in speeding up theorising and generating assertions in the findings.

### 7.1.3 School Context

School D, a new senior school for Year 11 and 12 students, located in a lower socio-economical suburb and industrial environs in metropolitan Perth, is a leader in state and national senior secondary education. Managed by an administrative team headed by the principal with a vision for innovation, School D highlights its ICT-rich learning environment and work-based learning for career or further study through TEE or TAFE. The school aims at linking students' learning to the part-time work they may undertake while studying and allowing the graduates to enter a career immediately or to further their study.

Through initial personal contact, I visited the school in November 2001 to demonstrate the *BioLogica* software and introduce my research to the teachers. I met Ms Elliott who appeared to be very interested in using *BioLogica* in her Year 12 TEE classes in 2002. As my ongoing research involved the use of interactive multimedia in teaching and learning biology in Year 12, the principal offered me warm support when Ms Elliott agreed to participate in my proposed project in 2002. All participating 9n =

17) except two had English as their first language and their age was from 16 to 18 years when the research was conducted.

### 7.1.4 Data Collection, Analysis and Interpretation

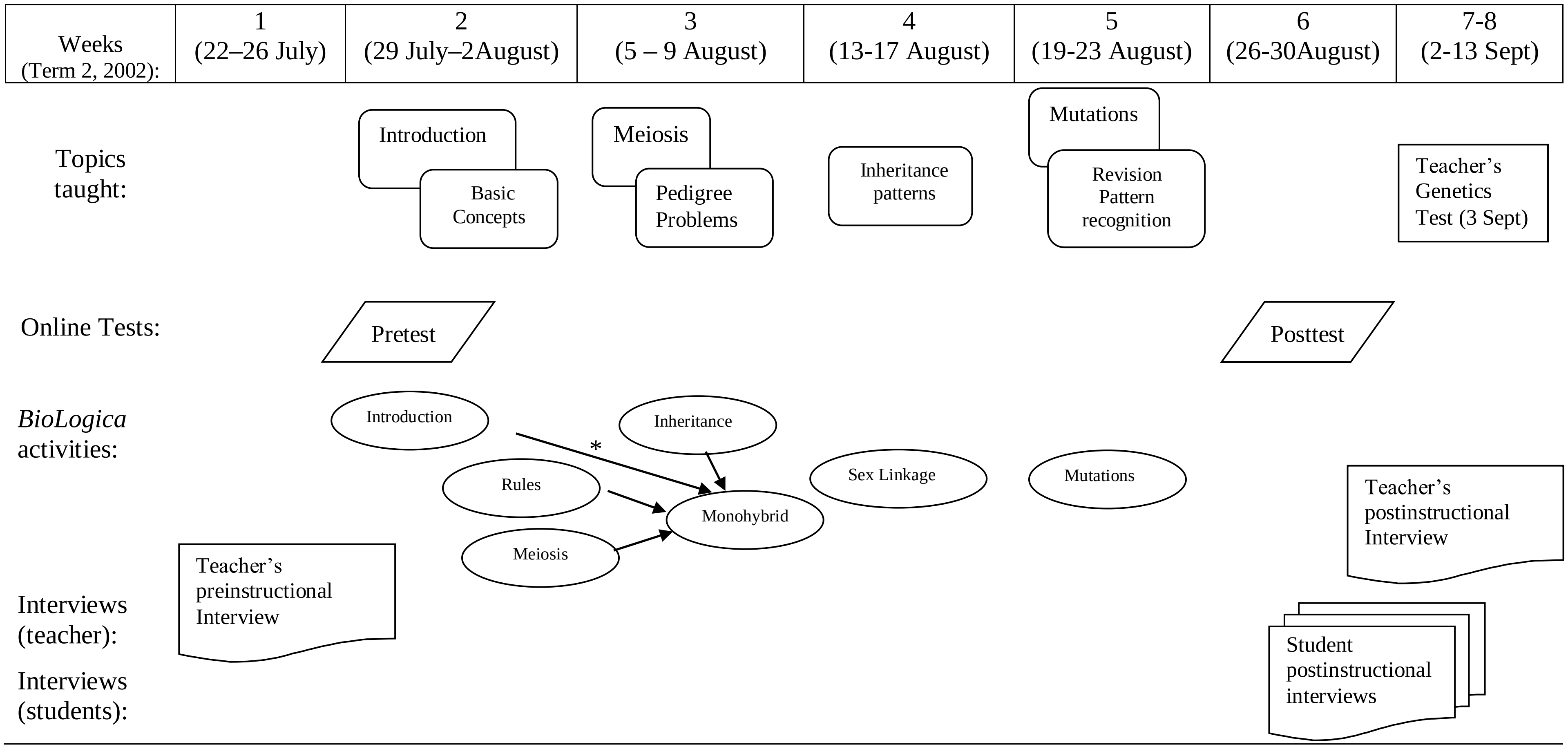
Before Term 3 (July, 2002), I had two short meetings with Ms Elliott to plan for the research and organise the students' participation documents. We started a collaborative working relationship and rapport that was to make research in this case study part of Ms Elliott's teaching and her students' learning.

As in the previous case studies, online and test/questionnaire, interviews, and classroom observations were major sources of data collected, analysed and interpreted. Ms Elliott initially planned to use the online discussion forum but was later too busy to do so and the web course was used only for delivering the researcher's online tests. One lesson in each class and several computer sessions were audiotaped and fully transcribed verbatim for subsequent analysis and interpretation. I interviewed Ms Elliott before and after instruction. As for the 17 students, all were invited to the postinstructional interviews but three students were absent and one did not wish to be interviewed. Students had unlimited access to the *BioLogica* software in the ICT-rich environment with high quality IT support. A complete set of log files tracked all students' interactions with the computer-based activities. Figure 7.1 is a composite diagram showing the chronological sequences of the above events and processes for the Year 12 Human Biology.

In the following sections, data are analysed and interpreted under particular conceptual themes or patterns relating to one or more specific research questions in this case study. In each section of the analysis and interpretation, confirming and disconfirming evidence from multiple sources are used to support or refute the themes and patterns identified. These themes and patterns are synthesised in a later section to generate the assertions for the findings of this case study.

## 7.2 Teacher's Beliefs, Expectations and Implementation

During the three to four weeks of teaching genetics, Ms Elliott integrated and implemented *BioLogica* activities as a major part of teaching. No other classes in the previous case schools had used so many *BioLogica* activities as did Ms Elliott's (see Table 7.2).




*The arrows show that *Monohybrid* activity requires the represented levels and representation tools in four previous activities

*Figure 7.1* Chronologically-ordered matrix of events of teaching and research in Year 12 Human Biology class in School D (see Appendix 1, Table A1.7.1 for details).

She justified her actions in the preinstructional interview, "I will use most of those programs because they are what I need to teach and [what] students need to understand ".

### 7.2.1 Ms Elliott's Beliefs, Expectations and Integration

Ms Elliott had tried out most of the *BioLogica* activities before teaching began. She told me in the preinstructional interview a number of reasons for using the *BioLogica* activities despite the tight time constraints imposed on the two TEE classes.

Table 7.2

*Summary of BioLogica Activities used by School D Students*

| *BioLogica* Activities | Activities Actually Used in Class | |
|---|---|---|
| | Biology Class [a] (*n* = 6) | Human Biology Class [b] (*n* = 11) |
| *Introduction* | | X |
| *Rules* | X | X |
| *Meiosis* | X | X |
| *Inheritance* | X | X |
| *Monohybrid* | X | X |
| *Mutations* | X | X |
| *Mutation Inheritance* | X | |
| *Dihybrid* | X | |
| *Sex Linkage* | X | |
| *Scales* | X | X |
| Total number | 9 | 7 |

[a] The sequence of use did not follow the top-down order given in the first column but the order as follows: *Meiosis, Monohybrid, Dihybrid, Sex Linkage, Inheritance, Rules, Mutations, Mutation Inheritance* and *Scales.*
[b] The sequence of use followed the top-down order given in the first column.

First, Ms Elliott thought that *BioLogica* is motivating as she said, "I find a significant part of the class don't enjoy [learning] genetics… and I find that quite hard [to teach] because they don't seem to think that it is important." and that "[*BioLogica*] being very visual I think will really help." She also believed that *BioLogica* is more advanced and more interactive than another computer program that she had used in teaching genetics in the previous year, and expected that *BioLogica* would give direct feedback to the students, that is really important, and they will then be able to know [the answer] right there." From what she said above, it appeared that she had identified two salient features of *BioLogica*, namely visualisation and instant feedback, as did most teachers and students in the previous case studies. These salient features were found to be intrinsically motivating and useful for understanding (see Chapter 4 and 7.6 below).

Second, her differential integration was meant to support the Human Biology class. At the planning stage, she carefully selected and sequenced the activities for the two classes: nine in the Biology class but only seven in the Human Biology class (see Table 7.2). The Human Biology students would not use the activities *Dihybrid*, *Mutation Inheritance* and *Scales* but they would use an easier activity *Introduction*. Her actions were in agreement with her beliefs about the student difficulties as she said in the preinstructional interview, "I find particularly with Year 12 Human Biology that there is a significant proportion of the class that do find genetics problems hard … those inheritance patterns". She expected that *BioLogica* could provide "one-to-one [interaction] which is almost the situation that your're getting and is a lot more beneficial, then trying to teach the whole class." She justified her actions as follows:

> [T]here seems to be this slight division in that Biology tends to attract a slightly higher achieving student than Human Biology. And so therefore, a lot of Human Biology students find it, the genetics section harder, um, than the Biology students do. Even though basically it's almost identical, the content. (Ms Elliott/Preinstructional Interview)

### 7.2.2 Ms Elliott's Implementation

The teaching of genetics in the Biology Class began one week earlier than in the Human Biology Class. Over three to four weeks in each class when genetics was being taught, I observed most of the lessons (see Table A1.7.1 and A1.7.2 in Appendix 1). Field notes and reflective journals were written for every observation, and expanded right afterwards. Ms Elliott and I had brief daily discussions and weekly planning to make the teaching with *BioLogica* sensitive to students' learning needs.

In both classes, Ms Elliott taught for half of the one-hour lesson in the classroom where she usually had whole class and group discussion about a topic related to the *BioLogica* activity to be used in the next half of the lesson. The students also used worksheets or the textbook or other material. Then, they went over to the adjoining computer room to work on one *BioLogica* activity after which they often were asked to return to the classroom for a debriefing session or follow-up discussion. Classroom observations indicated that Ms Elliott's actions were commensurate with her beliefs.

When asked how much support she would give to the students at the computer, Ms Elliott said the following:

> I'm going to let the [*BioLogica*] program itself be self-explanatory. And for the Biology class, they have better background knowledge than the Human Biology class. I'll probably give them [the Human Biology class] a little bit of background knowledge. With some of them… I'd like to just let them actually do the finding out, and if then they come up with a problem then I can help… So again, it's just seeing how the program goes and how the students relate to that, whether they do need that additional stepping [assistance], or whether they feel comfortable at going straight in and just using the information that's on the program. (Ms Elliott /Preinstructional Interview)

An interpretation of the above quotes reveals that not only did Ms Elliott know her students' learning difficulties well but she also appeared to use some constructivist ideas as referents in thinking about how much scaffolding she would provide students at the computer. As discussed in Chapter 2, research into student learning with multiple external representations (MERs) has shown that it is within a constructivist approach to afford students with appropriate scaffolding if the function of MERs is to encourage deeper understanding (Ainsworth, 1999). Further, Ms Elliott appeared to suggest, without saying explicitly, the use of a Vygotskian perspective to provide students with learning opportunities within their own zone of proximal development (ZPD) and that the teacher's role is to afford support so that students can do a task slightly higher than their particular ZPD. Specifically, she commented on "whether the students do need that additional stepping [assistance] or whether they feel comfortable at going straight in" (Preinstructional Interview). Classroom observations in the Human Biology class showed that she did provide scaffolding to those students who needed additional assistance before and during the *BioLogica* activities (see section 7.4.6) and that her good knowledge about the software enabled and empowered her to support students with confidence in a way not previously observed with other case teachers (see Chapter 9).

### 7.2.3 A Vignette: What's Happening in a Human Biology Lesson?

The following vignette is an episode about the classroom discourse in the Human Biology class based on my field notes and a segment of the verbatim transcript of the lesson:

> It was 5 August 2002, a Monday, the lesson started at 3:30 pm and would end at 4:30pm, a time quite unusual for other schools. School D runs on an eight-lesson time-table with no lunch break to give flexibility for students who are working part-time. My helper Susan [28] was in to help record the lesson and later transcribe the audiotapes. Soon the eleven students were seated (see Figure 7.2). (Field notes on 5 August 2002)

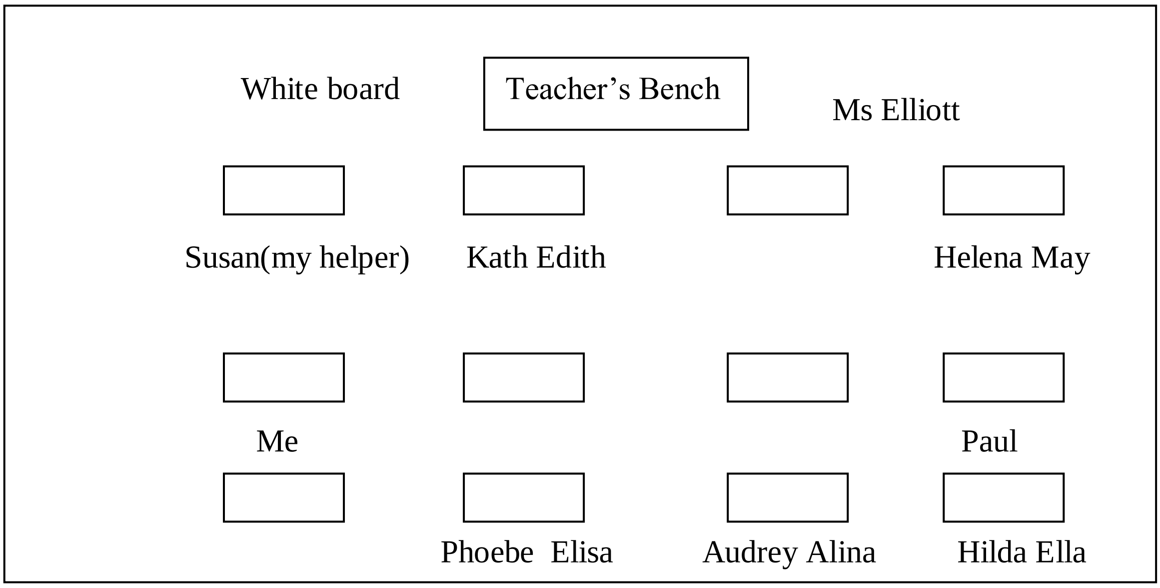



*Figure 7.2* Seating plan of the Human Biology students in the classroom on 5 August 2002.

The teacher had taught for 15 minutes by going over the homework from the textbook. A solution for a cross of Bb x Bb and the predicted genotypic and phenotypic ratio using the Punnett square method had just been discussed. Next, before the students went over to the adjoining computer room to work on the *BioLogica* activity *Inheritance*, the teacher had the following dialogues with the students:

---

[28] Susan was one of the two helpers supporting my classroom observations (see section 1.6 and footnote 2).

Teacher: Okay. Um, what I want to do, just before we go on [to use *BioLogica*], is I would like somebody just to go through with meiosis. What is the process of meiosis first of all ? What happens in meiosis?

Student 1: Isn't it when the cells (join).

Teacher: Cells join?

Student 2: No, (by division).

Teacher: They have to divide, okay. What, Kath, which cells? They're the?

Kath: Gametes.

Teacher: Gametes. Okay, it is a process which occurs in the gametes only, so we're talking about sperm and the ova or the egg. And basically what happens to the chromosome number?

Kath: It halves.

Teacher: It halves. And that's to allow fertilisation to occur, so that then you have half the number of chromosomes, with, so that when you have fertilisation you have a complete set of chromosomes, which in humans is how many.

Student 3: Twenty-three.

Teacher: Twenty-three pairs or forty-six. Okay. Um, (something) in um year twelve, the syllabus, we don't have to go through the stages of meiosis.

Student 4: Don't we?

Teacher: No. We don't have to know those stages. All you have to know is what meiosis is, and the fact that it is produced in the gametes, and the fact that it produces half the number of chromosomes. What we're going on to do today is the inheritance, so if you go, like we have been doing, to get into *BioLogica*, and then go down to the inheritance. And that is going through, more of this topic work, so hopefully it will help consolidate this type of work a little bit more. So if we go in there, take your file paper with you so that you can jot down a few notes as you're going through. [Sound of class moving into the other room]

The above classroom discourse consists of two parts. First, the teacher initiated a discussion about the meiosis process that the students had recently learnt in the classroom and had completed a corresponding *BioLogica* activity *Meiosis*. Her question “What happens in meiosis?” (line 3) probably evoked the image of meiosis with which the students made sense of the different entities she used in the talk that followed. Two themes emerge from this analysis. First, as Ogborn et al. (1996) put it, the teacher evoked these images of meiosis as resources for explaining the following entities of genetics she had been constructing over the past two weeks: *gametes* (Line 8), *sperm* and *ova* (Line 10), *chromosome number* (Line 10), *fertilisation* (Line 12), and *complete set of chromosomes* (Line 13-14).

Second, according to Lemke’s (1990) dialogue patterns (see section 2.3.4), the above teacher-student dialogues were typically of a pattern known as “Triadic Dialogue” (p. 217) in which the teacher asks a question, calls on students to answer it, and then evaluate their responses. Examples are found dialogues in lines 3 to 5, and lines 10 to 12. Despite the Triadic Dialogue being teacher-controlled, they might serve to didactically link the verbal-textual representations of genetics (the terminology) to their visual-graphical representations of genetics (graphic images of those entities) in the *BioLogica* activities. Within a sociocultural perspective of Vygotsky (1962; 1978), the teacher's dialogic interactions with students here may help students to internalise their understanding (intramental function) of the MERs through their participating in social interactions (intermental function) in classroom discourse such as the above (Werstch, 1985; Werstch & Stone, 1985; Wertsch, 1991).

Further, as instructional strategy, such a pre-session discussion might help students to benefit more when they next worked on the activity *Inheritance*. In particular, Ms Elliott believed that the Human Biology students were likely to learn more from *BioLogica* activities because they had both the difficulties in understanding the genetics knowledge as well as understanding the tools representing that knowledge in multiple modalities. The activity *Inheritance* utilises the pedigree (family tree) to introduce the random assortment of the alleles during meiosis and probability in determining the inheritance of traits through generations (Concord Consortium, 2002). Consequently, *Inheritance* introduces the necessary *BioLogica* tools needed for manipulating the MERs in the *BioLogica* activity *Monohybrid* that the Human Biology students would do on the following day (6 August 2002).

On the basis of the preceding sections, I generated two assertions in response to Research Question 7.1.

*Assertion 7.1*

*The teacher integrated and implemented BioLogica in her teaching unit of genetics to motivate her students' learning, engender their understanding, and supported their problem solving in their preparation for the-end-of-the year Tertiary Entrance Examinations (TEE).*

As in section 7.2, Ms Elliott talked about her beliefs and expectations in planning to use *BioLogica* in her teaching to motivate and support her students in learning genetics.

*Assertion 7.2*

*Although the teacher used some social constructivist ideas as referents for her actions in teaching with multiple representations, she was unable to scaffold her students as she had wished when implementing the BioLogica activities because of the constraints of time and the pressure of the Tertiary Entrance Examinations (TEE).*

Further to Ms Elliott's preinstructional expectations, her actions — in selecting and sequencing the *BioLogica* activities for the two classes of differing interests and abilities (see section 7.2.2) and in implementing the activities (see section 7.2.3) — suggested that her referents were constructivist ideas. She believed in using some didactic instructions (see lesson vignette in section 7.2.3) and scaffolded hands-on experiences (see sections 7.5.3 and 7.5.5) and follow-up discussion to relate the students' learning with the Dragon genetics to human genetics.

## 7.3 Student Motivation and Learning

Although the online tests in this study did not have open-ended questionnaires on student perceptions, I conducted postinstructional interviews with 13 of the 17 students to elicit their perceptions about their experiences of learning genetics with *BioLogica*.

The following are students' perceptions about their learning experiences based on what they said in the interviews.

### 7.3.1 Genetics is Interesting but Difficult.

Six of the 13 interviewees perceived that genetics was interesting to learn for a number of reasons but most found the topic difficult. Four students mentioned, without being asked, that it was *BioLogica* that had made learning more interesting or easier. The major difficulty was about terminology and pedigree analysis of different inheritance patterns, particularly that of sex linkage.

### 7.3.2 Three Salient Features of *BioLogica*

Student responses to the questions about the three salient features of the *BioLogica*, namely, *visualisation, instant feedback* and *flexibility* (one can work at one's own pace), were generally positive (see Table 7.3). These surface features of *BioLogica* were first identified in the case study in School A (see Chapter 4). Four students pointed out a limitation of the *BioLogica* activities connected with the software design in that users are unable to return to a point of exit. Such a comment which none of the participants in the previous case studies had mentioned before may indicate the greater engagement of School D students in the *BioLogica* activities.

### 7.3.3 *BioLogica* was Both Intrinsically and Extrinsically Motivating

None of the 13 interviewees held negative perceptions about the experiences using the *BioLogica* activities. This outcome was despite a few students who knew that they did not make much progress in the researcher's online reasoning tests. The three most common reasons provided were:

(a) *BioLogica* is more interesting or less boring than normal classroom learning (7 interviewees);
(b) *BioLogica* is more interactive than reading textbooks (6 interviewees); and
(c) *BioLogica* Dragons is a novel entity for learning (4 interviewees).

The third reason which interviewees mentioned without being prompted was the perception that the *BioLogica* Dragons were not just motivators but useful tools for learning genetics. Their voices in Tables 7.3 and 7.4 support this claim. However, four students who were not interviewed might have held negative perceptions. Three were away for work experience in shops as part of the school program; the fourth, Kath, who had not made much improvement in genetics reasoning, did not wish to be interviewed.

The students' reasons for *BioLogica* being motivating were conceptually mapped to the five themes of intrinsic motivations. As can be seen from Table 7.4, Elisa talked about how her peer Phoebe had helped her. What Elisa said was supported by evidence from other data sources such as classroom observations and the transcript of their dialogues at the computers during the *BioLogica* activity

*Inheritance*. However, it is interesting to note that Phoebe did not appear to perceive peer support from Elisa as she said, "Um, no. 'cause I didn't really talk to my neighbour much." (Phoebe/Postinstructional Interview). Phoebe's scores in the online tests were the highest in the Human Biology class (see section 7.2.2). Peer learning between Helena and May will be analysed and interpreted in section 7.4.4.

Table 7.3

*Student Responses to the Questions about Three Salient Features of BioLogica*

| Salient Feature | Number of Students with Positive Response/Sample Quotes | Number of Students with Mixed or Negative Response/Sample Quotes |
|---|---|---|
| Visualisation | 12 | 1 |
| | "Yeah, well when you change the traits and stuff, you can see it." (Helena/Interview)"<br><br>"Um, I just think because there's visuals, that information is really simplified, and so that it can be understood easier. So I think that's good (Phoebe/Interview). | "Yeah. Um, I didn't really…when they show the genes and you can work them out… but other thing was that it didn't really help you that much."(Elisa/Interview) |
| Instant feedback | 13 | 0 |
| | "Yeah, it was good having instant feedback, 'cause you know when you've got it wrong or you've got it right…" (Alina/Interview)<br><br>"Yeah um, it is good. Like, from the computer, um, it just gives us like the answers and all that." (Paul/Interview) | |
| Flexibility/worked at one's own pace | 9 | 4 * |
| | "Yeh, that was good too, yeh, um we could do it at our own pace and at our own understanding, and Breed them [the Dragons] the way we wanted to do, that was good ." (Juvena/Interview) | "Well we've only got an hour to do it, like it would be good it you could save it, and then go back to it afterwards, but you can't." (Hilary/Interview) |

*Four students commented that they could not return to a *BioLogica* activity at the point of exit.

Perhaps the motivation for their active engagement in *BioLogica* activities (see Tables A1.7.3 and A1.7.4 in Appendix 1) was also extrinsic. All interviewees unanimously said that they believed that the interesting experiences of learning genetics with *BioLogica* helped them to do better in solving problems in TEE. Audrey, a low-achiever who had the greatest pretest-posttest gain in the researcher's online test (see section 7.8.2), said, “You can think back, and then you remember, 'Oh, I did that on the computer' (Audrey/Postinstructional Interview).

Table 7.4

*Intrinsic Motivations in Learning with BioLogica as Perceived by School D Students*

| Intrinsic Motivation | Number of Students (Pseudonyms) | Sample Quotes |
|---|---|---|
| Fantasy | 5 (Alina*, Margaret, Hilary, Bob, John) | “It doesn't matter 'cause you're not killing them anyway. It's not real” (Alina)<br><br>“[H]umans are boring, Dragons are more interesting (Bob) |
| Curiosity | 4 (Margaret, Hilary, Paul, Helena) | “’Cause they're different. They've got different characteristics than humans.”(Helena) |
| Challenge | 1 (Hilary) | “[B]ecause they [*BioLogica*] asked you to invent [create] a Dragon that has one horn or a tail or stuff like that, that was good.”(Hilary) |
| Control | 1 (Bob) | “Yeh, it was good like that with the Breeding and everything because you could make loads of crosses really easily, so you could see it really quickly, you can do it all yourself, to try and look for patterns yourself.”(Bob) |
| Peer Support | 5 (Alina, Audrey, Elisa, May*, Helena*) | “Yeah, because, at first I didn't understand how to use the genes. How you put them together, and Alina had to show me that, but then after that that was all right. Thank you Alina! (Audrey)<br><br>“Yeah um, mainly I agree. It's pretty easier if she's [her peer Phoebe] doing it... Then, I don't get to the program, I usually, go and ask her. She usually explains it to me.”(Elisa) |

*Based on classroom observation and transcript of their dialogues at the computers.

*Assertion 7.3*

***Students had high level of engagement in BioLogica activities because initially they were intrinsically motivated by the salient features of the BioLogica MERs. Subsequently, they became extrinsically motivated by their belief that the activities help their preparation for the Tertiary Entrance Examinations (TEE).***

Assertion 7.3 was generated in response to Research Question 7.3. The interviewees (13 of the 17 students) talked eagerly about how they were motivated by the salient features of *BioLogica* and how such features had helped in their learning (see section 7.3). Analyses of the observational data (see section 7.2.2; Tables A1.7.1 and A1.7.2 in Appendix 1) and documents, particularly log files records (Table A1.7.3 in Appendix 1), also suggested that they had high engagement in the *BioLogica* activities in almost every lesson during the genetics unit.

## 7.4 Interactions with the MERs

This section documents the analysis and interpretation of the Human Biology students' *Monohybrid* log files and the transcripts of their dialogues at the computer were interpreted to illustrate the three emerging themes: mindfulness, metalearning and peer tutoring.

The *Monohybrid* log files were selected for analysis and interpretation because this activity involved the content and tools of several activities—*Introduction*, *Rules*, *Meiosis* and *Inheritance*—which the students had just completed (see Figure 7.1). Also this was a common activity done by other classes in Schools A and C so that some cross-case comparisons may be possible. When a student had several log files, the most complete and earliest one was selected for analysis. The student-student and student-teacher interactions were analysed alongside the log files when they can be collated.

### 7.4.1 Usage of *BioLogica* Activities

Most students in the two classes completed the *BioLogica* activities required by the teacher as indicated by the log file records (see Tables A1.7.3 and A1.7.4 in the Appendix 1). When a student was absent in a lesson, he or she usually made use of a free lesson where the computer room was available to complete that missed activity. The number of log files of a student might not necessarily indicate the number of times he or she had actually completed the activities as some activities were incomplete. Table 7.5 shows an analysis of the log files of ten Human Biology students when they were engaged in the *Monohybrid* activity on 6 August 2002.

Table 7.5

*Analysis of the Log Files of Human Biology Students (Monohybrid activity on 6 August 2002)*

| | | | | | Number of Viewings of Chromosomes of | | | | | | | | Number of Attempts in Each Challenge | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Students | Time (minutes) | Number of interactions (mouse clicks/other selections) | Index of interaction (time per number of interactions) | Creating Baby Dragons without Viewing Chromosomes | Parents in Meiosis View | Parents in Pedigree View | Parents in Punnett Square View | Parents' Gametes in Meiosis View | Gametes in Fertilisation View | Parents and Offspring in Meiosis View | Total number of Viewings of Chromosomes | Challenge 1:To make plain-/fancy-tailed baby | Challenge 2: To create zygotes in tt X Tt Punnett square | Challenge 3: To select zygotes in tt x Tt Punnett square | Challenge 4: To create gametes and zygotes in tt x TT Punnett square | Challenge 5 : To select zygotes in tt x TT Punnett square | Challenge 6 : To select zygotes in Tt X Tt Punnett square | Number of attempts per challenge | Quiz (after Challenge 5):offspring outcome from tt x TT | Quiz (after Challenge 6) :offspring outcome from tt x tt | Total Score of Quiz | Type of Help Asked for | Type of Practice Asked for | Remarks |
| 1 | Alina | 22.1 | 39 | 0.57 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 5 | 1 | 1 | 8 | 1 | 1 | 1 | 2.2 | 1 | 1 | 2 | nil | yes | ttxtt cross |
| 2 | Audrey | 22.8 | 38 | 0.60 | 2 | 0 | 0 | 0 | 10 | 0 | 1 | 11 | 2 | 1 | 1 | 1 | 1 | 1 | 1.2 | 0 | 1 | 1 | nil | yes | ttxtt cross |
| 3 | Elisa | 22.3 | 67 | 0.33 | 0 | 0 | 0 | 3 | 6 | 0 | 1 | 11 | 1 | 1 | 35 | 1 | 1 | 1 | 6.7 | 0 | 1 | 1 | yes | nil | Pedigree |
| 4 | Ella | 6.2 | 33 | 0.19 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 1 | 4 | 1 | 1 | 1 | 1.5 | 1 | 0 | 1 | nil | nil | nil |
| 5 | Helena | 24.7 | 49 | 0.50 | 1 | 0 | 0 | 1 | 6 | 1 | 2 | 9 | 1 | 1 | 15 | 2 | 2 | 0 | 3.5 | 1 | 0 | 1 | yes | yes | Meiosis, Tails rule |
| 6 | Hilda | 17.0 | 38 | 0.45 | 0 | 1 | 0 | 1 | 4 | 0 | 1 | 6 | 1 | 1 | 1 | 6 | 1 | 2 | 2.0 | 1 | 1 | 2 | nil | nil | nil |
| 7 | Kath | 18.7 | 106 | 0.18 | 4 | 1 | 0 | 2 | 2 | 3 | 3 | 12 | 1 | 1 | 64 | 1 | 1 | 1 | 11.5 | 0 | 1 | 1 | yes | nil | Meiosis |
| 8 | May | 25.9 | 70 | 0.37 | 4 | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 2 | 2 | 16 | 18 | 1 | 1 | 6.7 | 0 | 1 | 1 | nil | yes | Tails rule |
| 9 | Paul | 14.3 | 36 | 0.40 | 1 | 1 | 0 | 0 | 8 | 0 | 0 | 10 | 1 | 2 | 1 | 1 | 1 | 1 | 1.2 | 0 | 1 | 1 | nil | yes | Tails rule |
| 10 | Phoebe | 13.2 | 31 | 0.43 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 7 | 2 | 1 | 2 | 1 | 1 | 1 | 1.3 | 0 | 1 | 1 | nil | nil | nil |

### 7.4.2 Mindfulness

One major purpose of the log files analysis was to look at students' mindfulness in interacting with the multiple representations. Mindfulness was first identified in the analysis of the log files of students in School A as discussed in Chapter 4. Mindfulness is "volitional, metacognitively guided employment of non-automatic, usually effort demanding process" (Salomon & Globerson, 1987, p. 625). From a perspective of cognitive psychology, Jonassen (2000) uses "mindtools" or "tools for engaging the mind" (p. 11) for interactive computer program such as *BioLogica*. He asserted that to benefit from the mindtools, "[l]earners must approach learning mindfully. And they must realise and execute personal intentions to learn and think and to regulate those processes." (p. 273). According to Salomon and Globerson (1987), mindful learning is characterised by the following activities: (1) suppressing initial responses and reflecting on aspects of the problems; (2) gathering, examining, and personalising information about problems; (3) generating and selecting alternative strategies; (4) making connections to existing knowledge and building new structures; (5) expending effort on learning; (6) concentrating; and (7) reflecting on how a task was performed.

As discussed in Chapter 3, the log file analysis was partly based on the method of Buckley (2001). First, the index of interaction (see Table 7.5) which is the time per interaction (number of mouse clicks or other selections) may indicate mindful learning although it is not possible to map this to the mindful activities listed above. This index is used to give a rough estimate of how mindful a student was when interacting with the MERs. However, without direct observation such as video capture, it is not possible to know whether a longer time between two mouse clicks is used in thinking through the task or just a off-task break. Second, as the activity *Monohybrid* requires students to use the conceptual link between genotype and phenotype (related to mindful activities (3), (4) and (5)) in tackling tasks and challenges, the number of instances of looking at the chromosomes of individuals or their gametes is probably one important criterion for mindful interactions with the MERs in developing genetics reasoning. Students with low prior knowledge, Helena, Elisa, Audrey, and Paul, who made substantial pretest-posttest gains in genetics reasoning (see section 7.8.2), all had total number of viewings of more than *eight* (see Table 7.5). However, Kath also had 12 viewings of chromosomes but had four instances of creating a baby Dragon without viewing the chromosomes of the games. The latter counts indicated that Kath did not have mindful interaction as she attempted to do some blind guessing of the outcome of a monohybrid cross. Further, Kath's Index of Interaction was the lowest in the whole class (0.18 minutes per interaction) (see Table 7.5), it may be argued that she regularly but briefly viewed the chromosomes without a great deal of cognitive effort. Furthermore, Kath's average number of attempts in tackling the challenges was also the highest (11.5 per attempt) (see Table 7.5). Therefore, the results of log files analysis do suggest that Audrey was likely a mindful learner but Kath was probably not. Unfortunately, this claim can only be partially substantiated because there was no further investigation into Kath's mindfulness as she did not wish to be interviewed.

### 7.4.3 Metalearning

As the log files analysis in Table 7.5 shows, seven of the 10 Human Biology students sought either Practice (see Figure 7.3) or Help in the program that subsequently provided them with some drills or hints before they went through the main activity.

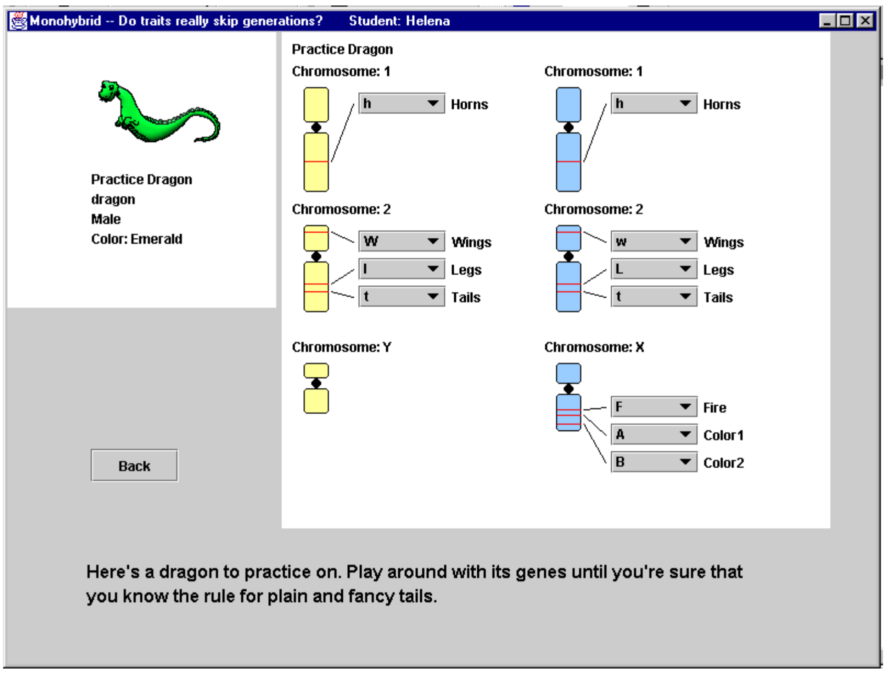



*Figure 7.3* Snapshot of the *BioLogica* activity *Monohybrid* showing a practice session for the rules of the tail shape in the Dragon.

Whereas May sought Practice, Helena sought both Practice and Help. These can be interpreted as metacognitive strategies (White & Gunstone, 1989) which are conducive to learning for understanding when completing the *BioLogica* tasks and challenges. Further, such actions of the students were also indicative of their mindfulness (Salomon & Globerson, 1987) while interacting with the multiple representations. Interestingly, the peers were found to use the same strategy probably because one peer followed what the other did. For instance, peers May and Helena both used *Tails Rule* Practice (see Figure 7.3) and peers Alina and Audrey both used *tt x tt Punnett square* Practice (see Table 7.5). Helena and Audrey, who had the lowest pretest scores across two classes, made the most substantial gains in the posttest (see 7.8.2). They might have benefited from the metacognitive strategies that they shared with their peers.

### 7.4.4 Peer Tutoring: A Vignette of Helena and May

*Peer support,* an interpersonal intrinsic motivation (Malone & Lepper, 1987), first identified in School A, became an important theme in School D, for example, Audrey whose peer was Alina mentioned about peer support (see Table 7.4).

Classroom observations indicated that peers, such as Helena and May, Audrey and Alina, were always seated together in the classroom (see Figure 7.2 in section 7.2.5) or in the computer room (see Figure 7.6 in section 7.2.5). Multiple sources of data indicated that peer support was important in fostering collaboration from which both peers benefit in their learning. Audiotape recordings of dialogues between the dyads documented collaborative peer learning at the computer during the *BioLogica* activities illustrated peer learning when the transcript was analysed alongside the log files that track their interactions with MERs.

The following analytic vignette is based on the audiotape transcript of the dialogues between May and Helena when they worked together, though using their own computers, on the activity *Monohybrid* (see Table 7.6). The transcript was collated alongside the corresponding segment of Helena's log file as shown in Table 7.6 (also see Figure 7.4 depicting the computer activity related to this episode).

Table 7.6

*Dialogic Interactions between Helena and May during the BioLogica Activity Monohybrid (also see Appendix 3, Document A3.7.1 Lines 61-97)*

<table>
<tr><th>Time</th><th>Transcript of Dialogue</th><th>Helena's Monohybrid log file segments</th></tr>
<tr><td>16:11:43</td><td>1 Helena: Ooh. Exciting. Hey, he's got a weird tail. He's got a tail like his mum.</td><td><date> 2002.08.06.16.11.43 08/06/02 | 16:11:43 </date></td></tr>
<tr><td></td><td>2 May:Okay, now you have to try and get like a fancy tail.</td><td>Made a plain-tailed baby and looked at chromosomes.</td></tr>
<tr><td></td><td>3 Helena:Okay.</td><td></action></td></tr>
<tr><td></td><td>4 May: So just do the same thing. I think that's-.</td><td><action></td></tr>
<tr><td></td><td>5 Helena:Is that big T?</td><td><date> 2002.08.06.16.11.55 08/06/02 | 16:11:55 </date></td></tr>
<tr><td></td><td>6 May: Big T and little t.</td><td>Looked at mother's gametes in meiosis view.</td></tr>
<tr><td></td><td>7 Helena:I don't have any big ts.</td><td></action></td></tr>
<tr><td></td><td>8 May: Are you in the mother?</td><td><action></td></tr>
<tr><td></td><td>9 Helena:Yeah.</td><td><date> 2002.08.06.16.12.18 08/06/02 | 16:12:18 </date></td></tr>
<tr><td></td><td>10 May: Okay, use a little t. And now you have to go back out. You</td><td>Looked at mother's gametes in meiosis view.</td></tr>
<tr><td></td><td>11 have to put that baby back. Okay, now do it.</td><td></action></td></tr>
<tr><td></td><td>12 Helena:Can I do that one?</td><td><action></td></tr>
<tr><td></td><td>13 May: Yep. Now do the other side and choose a big T.</td><td><date> 2002.08.06.16.12.30 08/06/02 | 16:12:30 </date></td></tr>
<tr><td></td><td>14 Helena:There you go.</td><td>Looked at father's gametes in meiosis view.</td></tr>
<tr><td>16:12:37</td><td>15 May: Okay, now go next.</td><td></action></td></tr>
<tr><td></td><td>16 Helena:(hm).</td><td><action></td></tr>
<tr><td></td><td>17 May: Okay now that (suits us .. female Dragons).</td><td><date> 2002.08.06.16.12.37 08/06/02 | 16:12:37 </date></td></tr>
<tr><td></td><td>18 Helena: How cool.</td><td>Made a fancy-tailed baby while looking for one.</td></tr>
<tr><td></td><td>19 May?: Oh look. I have a plain tail.</td><td></action></td></tr>
<tr><td></td><td>20 Helena: Where're mine?</td><td><action></td></tr>
<tr><td></td><td>21 May: If you use the same two Dragons again do you think…</td><td><date> 2002.08.06.16.12.58 08/06/02 | 16:12:58 </date></td></tr>
<tr><td>16:13:45</td><td>22 Helena: Mine is different to yours.</td><td>Made the first baby in pedigree view. It's got a fancy tail, so we're looking</td></tr>
<tr><td></td><td>23 May: you'll get a fancy tailed baby. Oh there you go. After three</td><td>for a plain-tailed one.</td></tr>
<tr><td></td><td>24 tries you get a fancy-.</td><td></action></td></tr>
<tr><td></td><td>25 Helena:What do you do? Mines different to yours.</td><td><action></td></tr>
<tr><td></td><td>26 May: What have you done? Okay, click off. Now do the same thing</td><td><date> 2002.08.06.16.13.45 08/06/02 | 16:13:45 </date></td></tr>
<tr><td></td><td>27 as you did to get the first one. Go from the circle. The black circle</td><td>Got a plain-tailed Dragon in 2 tries. Next cross will have 30 offspring.</td></tr>
<tr><td></td><td>28 Helena: Whoops.</td><td></action></td></tr>
<tr><td></td><td>29 May: The little black circle, and go to that white square. There you go.</td><td><action></td></tr>
<tr><td></td><td>30 Helena: Mm hm. You do the same thing?.</td><td><date> 2002.08.06.16.14.10 08/06/02 | 16:14:10 </date></td></tr>
<tr><td></td><td>31 May: But you got it [a plain-tailed] after two tries. (Reading from screen) 'A</td><td>Created a total of 32 offspring, of which 18 have plain tails and 14 have</td></tr>
<tr><td></td><td>32 question for you. If you made say 30 more babies how many do you</td><td>fancy tails.</td></tr>
<tr><td></td><td>33 think will have fancy tails?…what did you do?…'</td><td></action></td></tr>
</table>

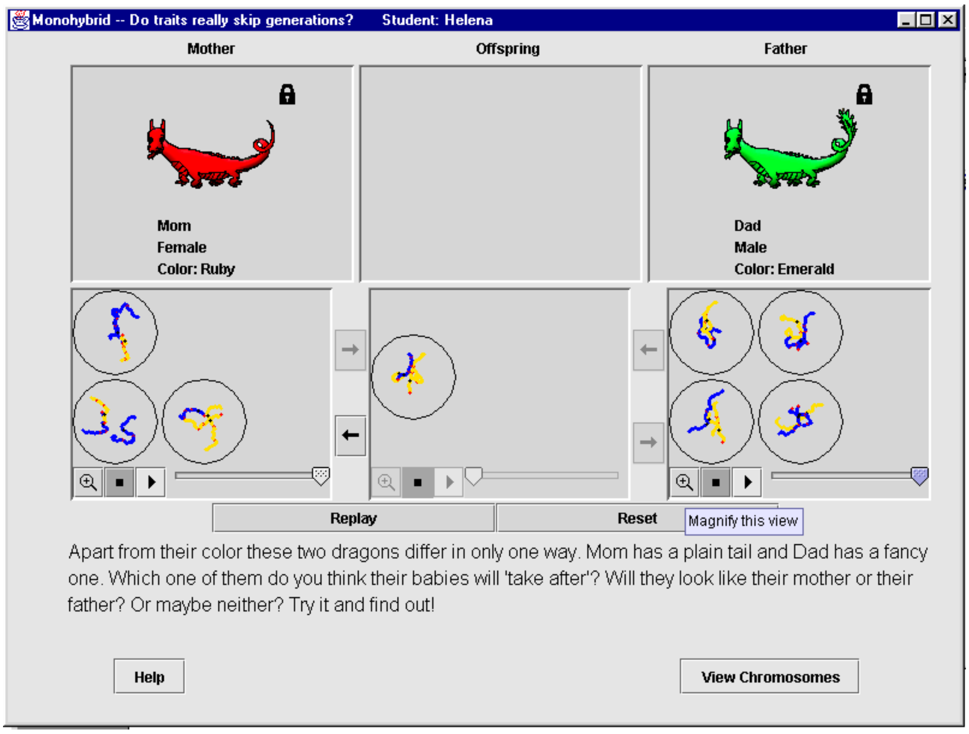



*Figure 7.4* Snapshot of the *BioLogica* activity *Monohybrid* showing a Meiosis View for Breeding a baby Dragon of a particular tail shape.

In the first part (lines 2-18), May acted as a peer tutor (Damon & Phelps, 1989) in guiding Helena through the activity to create a fancy-tailed baby Dragon from the given parent Dragons. The father and mother's phenotypes and genotypes were respectively *fancy-tailed* and *Tt*, and *plain-tailed* and *tt*. Helena had to select the correct gametes (one with T and one with t) as what May said, "Big T and little t" (line 6) while viewing the chromosomes using the Magnifying Glass (see Figure 7.4) and to reset the Meiosis View for each *breeding* when she said, "And now you have to go back out. You have to put the baby back." (lines 10-11).

In the second part or *Challenge 1* (see lines 9-33 in Table 7.6; also see the log files analysis in Table 7.5), Helena had to create a *plain-tailed* Dragon from the same two parents as required by *BioLogica*. *Challenge 1* (see Table 7.5) requires students to use the Pedigree View without being able to control meiosis process as in the first part (see Figure 7.5). This challenge is for students to learn about the random distribution of gene alleles during meiosis.

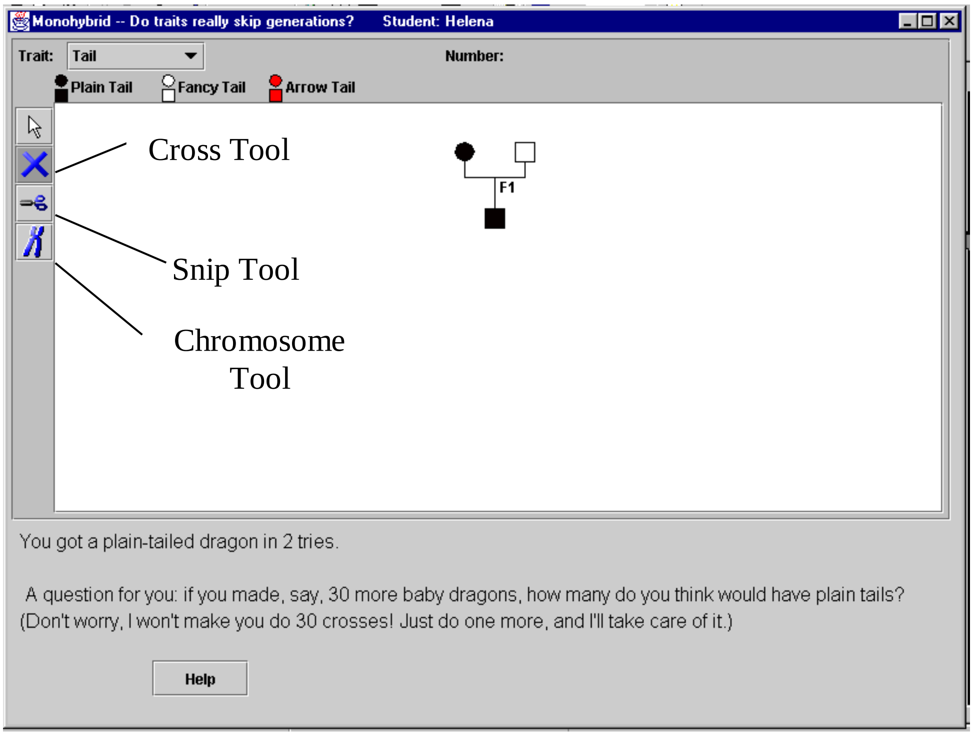



*Figure 7.5* Snapshot of the *BioLogica* activity *Monohybrid* reconstructed based on the corresponding log file of Helena (from time stamps 16:13:45 to 16:14:10).

As May's task (creating a fancy-tailed Dragon) differed from Helena's (creating a plain-tailed Dragon), Helena became perplexed and probably a little diffident when she said, "Mine is different to yours." (line 22). Probably, *ambiguity* which characterises novel tasks (Treagust, Wilkinson, Leggett, & Glasson, 1991) was challenging Helena. At that very moment, May had just completed the task by getting a *fancy-tailed* Dragon in three trials at 16:13:22 as indicated by her log file (see Document A3.7.2 in Appendix 3) and so May encouraged Helena by saying "Oh there you go. After three tries you get a fancy-tailed." (May's advice was in fact misleading here as Helena was to create a *plain-tailed* baby Dragon!). Next, May guided Helena to use the Cross Tool (see Figure 7.5) to click "the first one" (line 27) and "Go from the circle. The black circle" (line 27) or the icon for the plain-tailed mum and then "go to the white square" (line 29) or the icon for *fancy-tailed* dad. Still Helena was puzzled and asked if May had done the same thing because she noticed that May's baby Dragon was different from hers as she repeated, "Mine's different to yours" (Line 25). Then finally Helena accomplished her task (line 31) at 14:13:45

(see Table 7.6) with a text display on the screen "You got a plain-tailed Dragon in two tries"(see Figure 7.5).

Accordingly to Damon and Phelps (1989), the kind of collaborative peer learning portrayed above had low equality of peer engagement indicating unequal contribution made by both peers towards their common tasks. However, their peer learning was high in mutuality as Helena and May had "extensive, connected and intimate discourse' (p. 40). In this discourse, Helena learnt from her peer in a secure and supportive environment within her proximal zone of development. In turn, May, a peer tutor, should also learn from the discourse by clarifying her ideas as consistent with many studies of reciprocal teaching research since the pioneer work of Palinscar and Brown (1984). Probably, even Ms Elliott, as Helena's teacher, might not be able to guide Helena as did her peer tutor May.

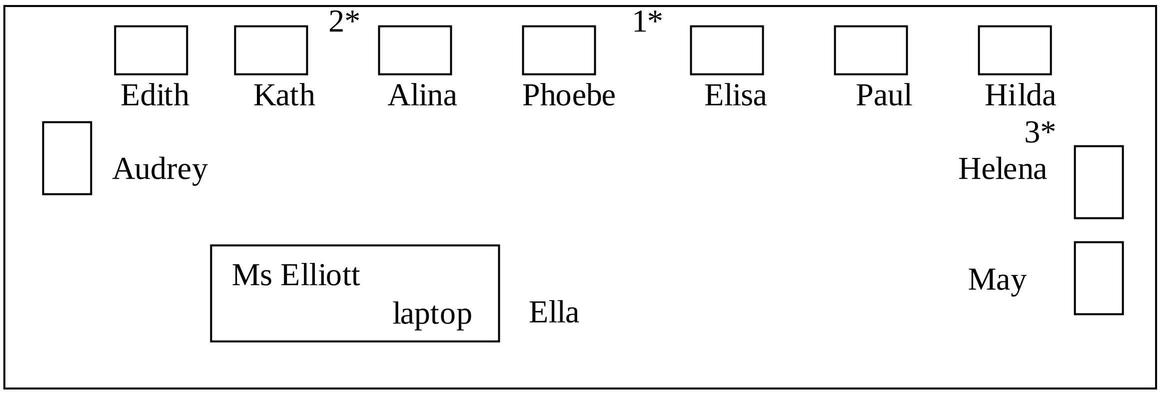
The above complexity in classroom student-student and student-computer interactions illustrate how the computer-supported collaboration can provide students with experiences that are useful for conceptual learning (see for example, Tao & Gunstone, 1999). In the postinstructional interview, Helena believed she learnt from *BioLogica* as she said, "Um, I remember doing meiosis last year. I didn't really understand it though. I understand it more now 'cause of the *BioLogica* program." Unfortunately, May was not free to come to the interview and I forgot to ask Helena about her experiences of working with May. However, Helena made substantial progress in her genetics reasoning as indicated by the pretest-posttest gain of 30.8% (see section 7.8.2).

In this analytic vignette, the verbatim transcript of that segment of dialogic interactions and their respective log file records provide rich and thick description about peer learning in a precise temporal sequence (see Table 7.6). As Kozma (2000) argued, the linked multiple representations are often not sufficient to support learning. The symbols of multiple representations "may best be used within rich social contexts that prompt students to interact with each other and with multiple symbol systems to create meaning for scientific phenomena" (p. 45). This vignette can be interpreted with Kozma's ideas. Further, the above analysis also provides some empirical evidence for the metaphor of cognitions being *socially distributed* (Dillenbourg, 1996). Accordingly, cognitive processes (such as genetics reasoning) are distributed between humans and machines within a Vygotsky's sociocultural perspective. Dillenbourg (1996) asserted that when two learners participated in a social system such as dyadic interaction at the computer, the culture of social system and the tools used for communication (language and the computer) "shape the individuals' cognition and constitute a source of learning and development" (p. 165).

### 7.4.5 Peer Learning: A Vignette of Alina and Kath

At 3:10pm on 5 August 2002, 11 Human Biology students were working with *BioLogica* in the computer room. While 10 of them were using the desktops (see Figure 7.6), Ella used a laptop computer. Based on my analysis of the log files, Ms Elliott required Kath who had not completed the activity *Meiosis* on the previous Friday to do it while other students could work on *Inheritance*. Kath was struggling with the third part of *Meiosis* or *Designer Dragons* while her neighbour (not her peer) Alina was engaged in another *BioLogica* activity *Inheritance*.

Kath who had created several dead Dragons soon got another one (see Table 7.7 and Kath's log file in Appendix 3, Document A3.7.3). The analysis of Kath's *Meiosis* log file indicated that she had altogether 13 instances of getting a dead male Dragon when she was required to create a live male one with some particular characteristics (determined by genes on the X chromosomes). This information provided more confirming evidence that Kath was not a mindful learner as discussed in section 7.2.2.




*Indicates the position of a tape-recorder

*Figure 7.6* Seating plan of the Human Biology students in the computer room on 5 August 2002.

Alina, who was not Kath's usual peer, appeared to make a piquant comment "Trying to kill both of the Dragons, cool!" (see Table 7.7). Kath became impatient but very curious about what was happening and could not figure out why her Dragons always died. This discrepancy event resulted in a kind of intrinsic motivation or *curiosity*, more specifically *sensory curiosity* that evoked in the learner "an optimal level of discrepancy or incongruity from present expectations and knowledge" (Malone & Lepper, 1987, p. 235).

Table 7.7

*Dialogue between Alina and Kath when Kath had Another Dead Dragon*

| Time | Transcript excerpt | Kath's *Meiosis* Log file snippet |
|---|---|---|
| 15:10 | 1 Alina: Trying to | <date>2002.08.05.15.10.26 08/05/02 \| 15:10:26 </date> |
| | 2 kill both of the | Made a dead Dragon. |
| | 3 Dragons cool! | </action> |
| | 4 Kath: What is | <action> |
| | 5 process that's | <date> 2002.08.05.15.10.31 08/05/02 \| 15:10:31 </date> |
| | 6 happening right now | Dragon is alive, but not the right gender and not the right number of legs. |
| | 7 Alina: Meiosis. | </action> |
| | 8 Kath: Meiosis? | <action> |
| | 9 Alina: Congratulations. | <date> 2002.08.05.15.10.41 08/05/02 \| 15:10:41 </date> |
| | 10 Kath: Isn't this how you | Dragon is alive, but not the right gender and not the right number of legs. |
| | 11 did? I'm just doing | |
| | 12 the same as you did. | </action> |
| | | <action> |
| | | <date> 2002.08.05.15.10.45 08/05/02 \| 15:10:45 </date> |
| | | Made a dead dragon. |
| | | </action> |
| | | <action> |
| | | <date> 2002.08.05.15.10.54 08/05/02 \| 15:10:54 </date> |
| | | Correct. Made a live male dragon with two legs. |

### 7.4.6 Teacher Scaffolding: A Vignette of *Emotive Power*

At 3:15 pm during the same lesson on 5 August 2002, (see Kath's *Meiosis* log file in Appendix 3, Document A3.7.3), Ms Elliott became engaged in a dialogue with Kath. (In that particular *BioLogica* task, the genotypes of the father and mother Dragons were respectively $X^BY$ and $X^BX^b$; and $b$, one of the recessive gene alleles that determine skin colour of the Dragon is lethal. A male baby Dragon with genotype $X^bY$, which is likely *50%* chance here, kills him.)

Kath: Okay, so chromosome one [Y chromosome], and so why doesn't he [father Dragon] have white [gene labels]?
Ms Elliott: Because she [mother Dragon] is a female. She only has two [X] chromosomes.
Kath: Well why doesn't he [father Dragon] have a white one [gene labels]? Ms Elliott: He does have a white one. See he doesn't have the actual white [labels] on his chromosome [Y]. He only has [it] on the X chromosome, his colour genes. So that's what you have to work out with the colour, how it's actually inherited.
Kath: All right, so this is a female.
Ms Elliott: And white [labels], because
Kath: recessive.
Ms Elliott: You need to work out which one of those colours will produce the dead Dragon. You only actually work out these colours, so either it's colour 1 or colour 2. That's what you need to work out. [pause]. So what can you tell me? About the recessive gene.
Kath: Just that one [colour gene 2].
Ms Elliott: You see that- with that one you get big B and the big B is dominant over the little b. So that's why it's [the female Dragon is not dead]
(Time: about 16:20)

The verbatim transcript of Kath's question "Why doesn't he have white?"(line 1-2), repeated again in line 5, first appeared difficult to interpret. However, when I carefully considered the context within which the discourse took place, it became clear that both were viewing the screen with colour cues and text labels (see Figure 7.7).

Kath did not understand why there were no *white* gene labels on the Y chromosomes the same as those—tiny white rectangles with the labels such as *f*, *A* and *B* connected by black lines to the X chromosomes—in the two left gametes (see Figure 7.7). A scrutiny of the log file segment corresponding to these dialogues further supports such interpretation.

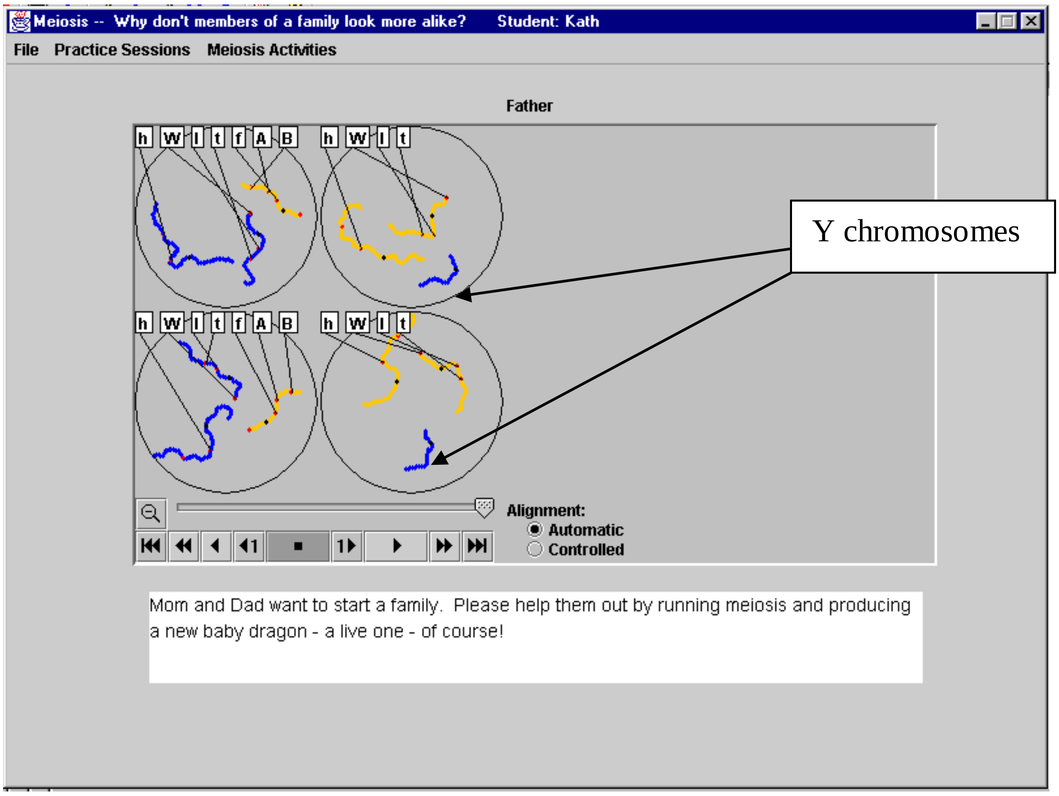



*Figure 7.7* Meiosis View showing the father Dragon's gametes with the Y chromosomes (indicated by arrows) that have no *white* gene labels.

Ms Elliott first explained to Kath about the difference in the male and female sex chromosomes and that the colour gene alleles *A/a* or *B/b* were found only on the X chromosome (lines 6-8). She needed to work out the inheritance pattern of the skin colour of Dragons (lines 8-9) and then she could next find out which colour gene alleles caused the death of a baby Dragon (lines 12-14). In explaining why a female baby Dragon would not die in this particular task, Ms Elliott crafted well to construct a new conceptual entity (Ogborn et al., 1996) of a lethal recessive gene by making use of the MERs as resources for explanation.

It should also be noted in the above classroom discourse that the dialogues did not conform to the common Lemke's (1990) Triadic Dialogue as discussed in section 7.2.5 but was rather a True Dialogue in which "teacher and students ask and answer one another's questions and respond to one another's comments as in normal conversation" (p. 217). As Lemke argued, whereas Triadic Dialogue that gives teacher's control over the talk which is more like *quizzing* and is dogmatic, True

Dialogue, which is rarest in classroom discourse, tends to better handle "many important issues of judgement and opinion in science"(p. 55).

The classroom context during the *BioLogica* activities appeared to foster such student-teacher True Dialogue in which students could freely interact with the teacher when they needed scaffolding. In the postinstructional interviews, Ms Elliott and 13 students who were interviewed (76 %) perceived that such teacher-student interactions at the computer helped student learning. This analytic vignette adds more supporting evidence to the claims about how the usefulness of classroom interactions to learning can be interpreted using a sociocultural perspective of Vygotsky (also see section 7.4.4).

As life and death is always an emotive issue, a dead baby Dragon due to a recessive lethal gene allele (colour gene b) constitutes a motivating learning task in a way similar to the "emotive power" (Fensham, Gunstone, & White, 1994, p. 261) of a science topic. In this vignette, I have portrayed how Ms Elliott made use of this emotive power to explain *sex-linkage*. Classroom observations indicated that Ms Elliott often afforded scaffolding to students, particularly the Human Biology students, while using the *BioLogica* activities, and that students liked to discuss Dragon genetics with Ms Elliott at the computer.

The preceding analytical vignettes provides grounds for generating an assertion (see Assertion 7.5) about the how mindfulness, metalearning, peer learning and teacher's scaffolding affect students' development of genetics reasoning which will be discussed in the next section.

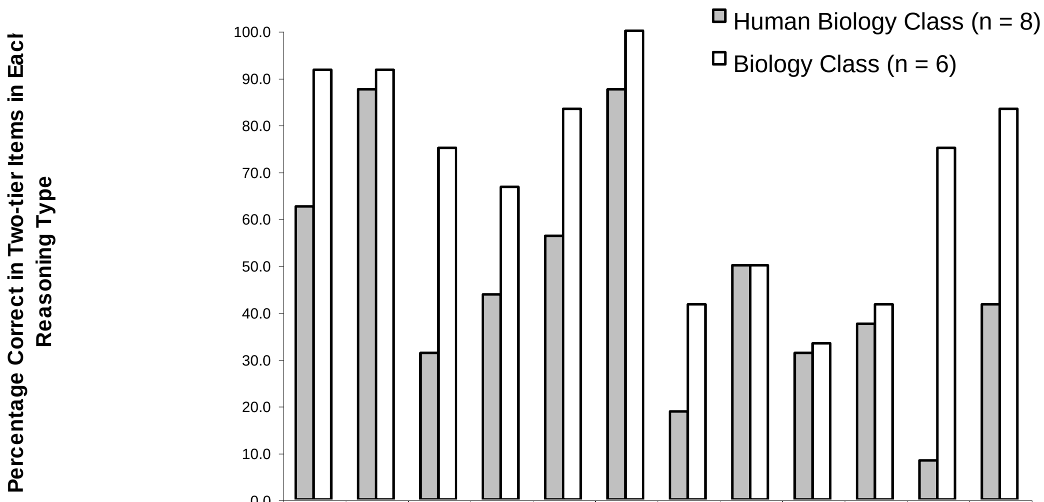
## 7.5 Genetics Reasoning

The pretest and posttest for School D were lengthened by increasing the parallel two-tier items from six to 13 items (two in each of the Types I to V and three in Type VI) including two items adapted from the reasoning tasks in the preinstructional and postinstructional interviews used in the interviews of the students in Schools A and C. Some items also were modified to match the requirements of Year 12 classes preparing for the Tertiary Entrance Examinations (TEE) (see Chapter 3 for details).

### 7.5.1 Class-wide Results and Interpretations

The pretest scores indicated a disparity in the prior knowledge of genetics reasoning across the two classes. The much lower pretest mean score (32.7%) of the Human Biology class was consistent with what Ms Elliott told me in the preinstructional interview before the students took the pretest. From this lower baseline (32.7%), the eight Human Biology students made substantial pretest-posttest gains (+24.0%) but their posttest mean (56.7%) was still lower than the pretest mean of the Biology class (61.5%). The smaller pretest-posttest gains (+5.2%) in the Biology class may be due to a *ceiling effect* of the testing instruments (Borg, Gall, & Gall, 1993).

Pretest-posttest comparisons were made between the students in the two classes in terms of the six types of genetics reasoning (see Figure 7.8).




| | Type I (pre) | Type I (post) | Type II (pre) | Type II (post) | Type III (pre) | Type III (post) | Type IV(pre) | Type IV(post) | Type V (pre) | Type V (post) | Type VI (pre) | Type VI (post) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Human Biology Class (n = 8) | 62.5 | 87.5 | 31.3 | 43.8 | 56.3 | 87.5 | 18.8 | 50.0 | 31.3 | 37.5 | 8.3 | 41.7 |
| Biology Class (n = 6) | 91.7 | 91.7 | 75.0 | 66.7 | 83.3 | 100.0 | 41.7 | 50.0 | 33.3 | 41.7 | 75.0 | 83.3 |

**Type of Genetics Reasoning**

*Figure 7.8* Comparison of genetics reasoning of students in Year 12 Human Biology and Y12 Biology classes.

The following patterns were identified in Figure 7.8:

(1) Similar to what was observed in other classes in the previous case studies in Schools A and C, there was a general trend that students found the genetics reasoning types progressively more difficult from Type I towards Type VI (see. Table 3.1 for the description of the reasoning types).

(2) Both classes made progress in all types of reasoning.

(3) The Human Biology class found the last three reasoning Types IV (effect-to-cause across generations), Type V (process reasoning within generation), and Type VI (process reasoning across generations) more difficult than Types I to III.

(4) Nevertheless, the Human Biology class did make substantial improvement in both Types IV and IV upon rather low base lines.

(5) Both classes made the least improvement in Type V items providing further evidence to support the claim that their ontological conceptual change was small.

Of particular importance in this case study is the fourth pattern above because in the previous case studies I was not able to find enough evidence to support the claim that *BioLogica* could support students with lower prior knowledge in learning genetics. Nor did the teachers' comments explicitly support this claim.

### 7.5.2 A Focused Analysis of Students with Lower Prior Knowledge

This section aims at examining how students with lower prior knowledge fared in their development of genetics reasoning when they were regularly engaged in computer-based MERs of the *BioLogica* activities. Expanded to more items, adapted for use in School D and improved to include online feedback in the posttest, the online tests in this case study should give a good indication of the students' genetics reasoning.

While the major focus was on the Human Biology class, the performance of the Biology students was also considered for comparison. Taught by the same teacher, these students worked on a similar set of *BioLogica* activities as regularly as did the students in the Biology class (see Table 7.2). The analysis attempts to interpret their learning outcomes in terms of the empirical evidence from several sources about their genetics reasoning and conceptual understanding. Partly based on the work of Tao and Gunstone (1999), students' pretest-posttest gains were categorised and ordered to identify more patterns and trends (see Table 7.8).

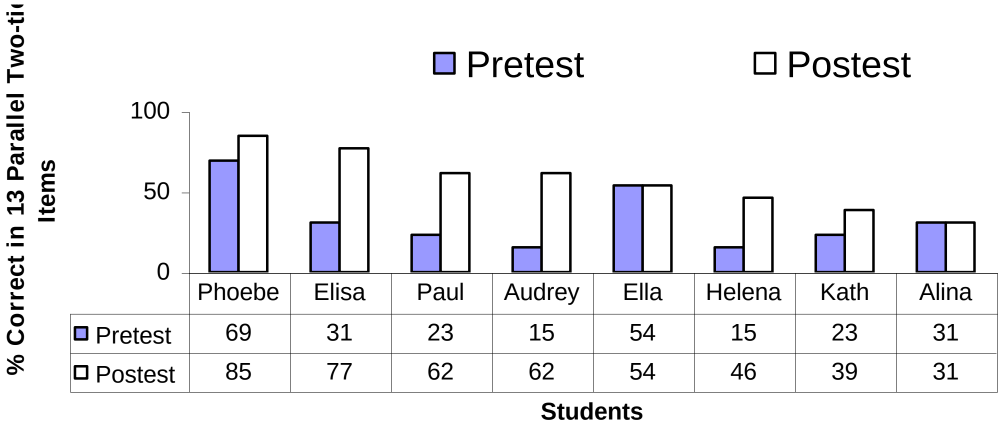
Table 7.8

*Grouping of School D Students based on Online Test Scores*

| Pretest Score ( Prior Knowledge) | Pretest-posttest Improvement | | |
|---|---|---|---|
| | < 10% Gain | 10-20% Gain | >20% Gain |
| High: | Karl (100; 100; 0) [a] | Phoebe (69; 85; +15) | |
| 50% or higher | Bob (77; 85; +8) | | |
| | Juvena (53; 46; -7) | | |
| | Hilary (54; 62; +8) | | |
| | Ella (54 ; 54; 0) | | |
| Low: | Alina (31; 31; 0) | Kath (23; 39; +16) | Elisa (31; 77; +46) |
| Less than 50% | John (39; 39; 0) | | Paul (23; 62; +38) |
| | | | Audrey (15; 62; +46) |
| | | | Helena (15; 46; +31) |
| | | | Margaret (46; 69; +23) |

[a] The three figures in the parentheses are respectively the pretest score, posttest score and pretest-posttest gain in percent.

As can be seen from Table 7.8, an arbitrary criterion of 50% was used in categorising students into two groups—low prior knowledge groups (with pretest score less than 50%) and a high prior knowledge group (with pretest score equal to or higher than 50%). The first pattern identified from this matrix is that most low prior knowledge students were in the Human Biology class (six out of eight) (see second row in Table 7.8). The second pattern that emerges from this table is that only one student (Phoebe from the Human Biology class) in the high prior knowledge group had pretest-posttest gains of 10% or more in contrast to the six out of eight low prior knowledge students who had such gains. While Elisa's gain (+46%) is the highest, the gains of Audrey (+46%) and Helena (+31%) who started with the lowest baseline of 15% (pretest score) are most encouraging. The within class pretest-posttest comparisons are graphically displayed in Figure 7.9.




| | Phoebe | Elisa | Paul | Audrey | Ella | Helena | Kath | Alina |
|---|---|---|---|---|---|---|---|---|
| Pretest | 69 | 31 | 23 | 15 | 54 | 15 | 23 | 31 |
| Postest | 85 | 77 | 62 | 62 | 54 | 46 | 39 | 31 |

*Figure 7.9* Pretest-posttest comparison student genetics reasoning within Human Biology Class.

As quantitative data, gains in test scores need to be viewed with caution because of the ceiling effect (Borg et al., 1993) caused by the online tests being too easy for some high-achieving students. As shown by the data in Table 7.8, Karl scored 100%, Bob scored 77% and Phoebe scored 69% on the pretest so that the posttest could not effectively measure their gains which they should have made in their learning due to the ceiling effect. Furthermore, scores of three students, John, Ella and Alina, remained unchanged and Juvena's score regressed. These instances constituted some disconfirming evidence that engagement in *BioLogica* activities might have contributed to students' genetics reasoning. I have argued in an earlier section that mere regular engagement in the computer activities might not necessarily result in cognitive learning. Whether of not students display mindfulness (Salomon & Globerson, 1987) is one plausible explanation for some students being unable to transfer their learning to other situations such as tests and examinations. In Ms Elliott's tests (slightly different in two classes), Alina's score of 78% was one of the two highest in the Human Biology class (see Table A1.7.5 in Appendix 1) whereas Ella's score of 41% was the lowest in the same class. Nonetheless, all students interviewed (*n* = 13) held positive perceptions about their learning experiences with *BioLogica* and believed that such experiences would help in answering the genetics question in the TEE.

Perhaps the students' performances observed in the online tests and the teacher's tests could only reflect their ability to use this competence in the tests but not their competence per se (Davidson & Sternberg, 1985). Using a Vygotskian perspective of the zone of proximal development (Vygotsky, 1978), I believe that peer effects and teacher scaffolding are important discursive activities that may be able to bridge the gap between what students are able to do and their performance. From the cognitive/computational perspectives, such discursive activities might also enhance the third function of MERs—construction of deeper understanding of genetics as argued by researchers such as Kozma (2000).

To summarise the findings based on in the preceding sections 7.4 and 7.5, two assertions were generated in response to Research Question 7.4.

*Assertion 7.4*

*Students with lower prior knowledge made more improvement in genetics reasoning than did those with higher prior knowledge but not all were able to improve when their level of engagement in the BioLogica activities was similar.*

This is the most important finding in this case study because the teacher working collaboratively with me intentionally supported the learning of students having lower prior knowledge with *BioLogica* used in an unprecedented way compared to the previous case studies (see sections 7.2, 7.2.5, 7.3.2, and 7.6). Although not all students with lower prior knowledge improved in their work, their positive perceptions and increased confidence are most encouraging in the whole study. The mismatch of effort and achievement in some students again provides some supporting evidence for the plausible explanation using the construct of mindfulness (see section 7.4.2).

*Assertion 7.5*

*Mindful interactions with the MERs, metacognitive strategies, peer learning, and teacher scaffolding within the students' zone of proximal development are important factors for developing genetics reasoning when students had regular engagement in BioLogica activities.*

## 7.6 Gene Conceptions

Students' preinstructional and postinstructional gene conceptions were captured by a parallel open-ended questionnaire item about what they knew about a gene before and after instruction (see Table 7.9) and two parallel two-tier questions in the online tests on Type V genetics reasoning (see Figure A1.4.3 in Appendix 1). No questions were asked about gene conceptions in the postinstructional interview—the only interview.

Table 7.9

*Pretest-posttest Comparison of School D Students' Gene Conceptions*

| Category | Gene Conception in Response to "What you know about a gene?" | Number of Students [a] | | | |
|---|---|---|---|---|---|
| | | Year 12 Biology Class | | Year 12 Human Biology Class | |
| | | Pretest ($n$ = 6)[b] | Posttest ($n$ = 6)[b] | Pretest ($n$ = 10)[b] | Posttest ($n$ = 9)[b] |
| 1 | A gene is from parents/grandparents | 2 | 4 | 4 | 1 |
| 2 | A gene determines a trait / characteristic /phenotype | 5 | 4 | 5 | 5 |
| 4 | A gene is part of a chromosome/chromatid | 3 | 3 | 0 | 2 |
| 5 | A gene is/part of DNA | 1 | 1 | 3 | 1 |
| 6 | A gene is information | 1 | 1 | 0 | 0 |
| 10 | Genes are affected by environment | 0 | 0 | 1 | 0 |
| 13 | A gene contains genetic code | 0 | 1 | 0 | 1 |
| 15 | A gene contains instruction determining characteristics | 0 | 0 | 0 | 1 |
| 16 | A gene can be dominant or recessive | 1 | 0 | 2 | 4 |
| 17 | Genes can be alleles | 1 | 4 | 0 | 3 |
| 18 | Productive instruction for making protein | 1 | 0 | 0 | 0 |
| 0 | Don't know/not answered | 0 | 0 | 2 | 0 |

[a] One student could have more than one conception.

[b] All six participating students took both online tests.

Given that genetics was not new to the Year 12 students as they had already studied the basic concepts in Year 10, it was not surprising that there was little change in their gene conceptions (see Table 7.9) which on the whole were not sophisticated according to the analysis provided by Venville and Treagust (1998).

Most students still conceptualised the gene as matter (a particle) more than as a process after instruction and their ontological conceptual change was thus small (Chi et al., 1994) (see Chapters 4 and 5).

## 7.7 Dragons for Constraining Interpretations of Phenomena

Drawing on the findings of Case Study Three in School C, I challenged each interviewee student to consider a negative view with a "Devil's Advocate Question" (Merriam, 1998, p. 79) which was about *BioLogica* being disliked by some other students because it is about Dragons not humans (see results in Table 7.10).

Table 7.10

*Human Biology Class Interviewees' Responses to the Devil's Advocate Question*

| Students of Human Biology class | Sample Quotes of Student Responses to the Question "Some students told me that they didn't *BioLogica* because it is about the Dragons not humans, what do you think?" |
|---|---|
| Alina | No, the Dragons are all right. They were cute. |
| Phoebe | Oh, I liked it [the Dragon]. I just liked the colours. [laughs] |
| | [It] was really good. Especially with the Dragons, 'cause I think you remember more with bright colours (laughs) |
| Ella | I thought it was cool. I liked them; it was different, interesting. |
| | Yeah because the Dragons were just were just representing people [humans] anyway, so. If you just take that information anyway, so I thought it was still really good |
| Paul | I don't really mind Dragons or anything |
| | I can relate the Dragons to the humans, because even though they're not humans, they have different genotypes probably, basically have kind of the same things. |
| Audrey | I liked it with the Dragons. Easier to understand. |
| Elisa * | It, hmm, could be good if it was humans 'cause then you know, um, it's like you can understand more; Dragons are like, fictional, But um, I guess it's all right. [I]f it was humans, though, it could be like, more real. |
| Helena | No, I liked the Dragons. |
| | 'cause they're different. They've got different characteristics than us, and, um, it's just different to use than humans. |

* Elisa was one of the only two interviewees (the other was Juvena from the Biology class) who partly agreed with the negative view in the Devil's Advocate question.

All interviewees except two disagreed with this view. Others said that they liked the Dragons and some explained that they were able to relate the tasks with the

Dragons to human situations (see Table 7.10). This learning situation was what Ms Elliott had expected of her students when they were engaged in *BioLogica* activities (see section 7.2.2). When Ms Elliott reflected in the postinstructional interview as will be reported in section 7.9.5, she thought that her students did like the Dragons and were able to relate the Dragon genetics to human genetics. Confirmed by evidence from both the students and their teacher, this emerged as an important theme related to the role of the MERs in student learning—the use of simple, colourful Dragons, co-deployed with explanatory text and interactive questions and answers, to constrain the interpretation of the more complex phenomena of human genetics. It appears that the Dragons in various MERs may link student motivation with student cognitive engagement and their development of genetics reasoning.

*Assertion 7.6*

*BioLogica Dragons are familiar constraining representations for interpreting the complex phenomena of human genetics that supports a learner's genetics reasoning. The constraining function of MERs in BioLogica Dragons supported some students with lower prior knowledge to make substantial improvement in their learning in terms of genetics reasoning.*

This assertion generated in response to Research Question 7.5 draws on multiple sources of data—the genetics reasoning online test results (section 7.5), the log files analyses (see section 7.4.2), the vignettes (sections 7.4.3 to 7.4.6), the students' and the teacher's perceptions (see sections 7.8 and 7.9). It was also generated in response to the unanswered question in the third case study in School C where those who disliked the Dragons did not improve in their genetics reasoning (see Chapter 6).

## 7.8 Students' Perceptions about their Teacher's Role

Postinstructional interview transcripts analysis indicated that, 13 students (seven in Human Biology class and all six in Biology class) who were interviewed generally held positive perceptions when they reflected upon their experiences of using *BioLogica* activities and their usefulness for learning genetics.

Most students perceived that Ms Elliott's integration and implementation of *BioLogica* activities for half of most of the lessons was useful to their learning of genetics. They did not prefer listening to teacher's talks in the classroom as Helena said, " I'd rather be on the computer though, than her [Ms Elliott] talking about it, 'cause I like the *BioLogica* [activities] better." But most students found Ms Elliott's briefing before the *BioLogica* activities useful. Helena said, "Um. Well I think it's good [for the teacher] to go through the actual steps, like one by one [rather] than just going all over the place." As well, these students believed that these interactive computer-based activities helped their preparation for the TEE. The Human Biology students also suggested ways to improve using *BioLogica* in teaching and learning of genetics as follows: (1) doing more activities; (2) talking less in class; (3) studying the textbook alongside *BioLogica* activities, and (4) providing a summary sheet to guide students working on the activities. Helena even recommended that *BioLogica* be used in the following year as students would like it.

## 7.9 Ms Elliott's Reflections and Comments

Based on the postinstructional interview with Ms Elliott and other anecdotal evidence from our daily conversations, I summarise in the following sections the seven major themes of the teacher's reflections and comments on her experiences teaching genetics with *BioLogica* as an integral part of student learning in her two Year 12 classes.

### 7.9.1 Learning Outcomes and Expectations

The outcomes from using *BioLogica* activities generally lived up to Ms Elliott's expectations, but to different extents, in the two different classes. Ms Elliott told me in the postinstructional interview:

> Well I've been really pleased with the way the students have been able to use the program, I think we've had two quite different groups… The Biology students have grasped the concepts a lot more quickly, and have been able to use the *BioLogica* program more efficiently than the Human Biol students...[Nevertheless] I feel that they [Human Biology students] have benefited a lot from using the *BioLogica* activities but I also feel that it's taken them longer to actually get to the point that [met] the objectives that they need to have achieved. (Ms Elliott/Postinstructional Interview)

Ms Elliott's reflections concurred with the my interpretation of the differing learning outcomes of the two classes from a different baseline (see Table 7.8)

### 7.9.2 Learning for Understanding and for Examinations

The time constraints imposed on Ms Elliott's teaching could only allow her to have a cautious trade-off of teaching to complete the curriculum for the examinations and teaching for understanding. Had she had more time, she would have done more for the Human Biology class to support their learning. She said:

> Unfortunately with the Human Biology class the syllabus was very very tight, so you don't have much time, and I think they have benefited hugely [from the *BioLogica* activities that] we have been able to run. Perhaps a little bit slower and we're doing [the *BioLogica*] activities and spend [more] time in the classroom going over that and then reinforcing it [the student learning] (Ms Elliott / Postinstructional Interview)

### 7.9.3 Two Salient Features of *BioLogica* and Learning

Consistent with what her students perceived, Ms Elliott considered that the two salient features of *BioLogica*, namely, visualisation and instant feedback (two recurring themes in all the previous case studies) which she had highlighted before instruction, had motivated and supported student learning at the computer.

### 7.9.4 Constraining Interpretations and Constructing Understanding

In terms of the three functions of multiple representations, Ms Elliott's reflections of her experiences of using *BioLogica* activities in the two classes of differing abilities were connected more to constrain student interpretation of phenomena of genetics (second function) and to encourage their construction of deeper understanding (third function) than to complement information and processes (first function). Lesson transcripts, handouts, assignments and tests all pointed to her emphasis on pedigree analysis in solving problems. Her selection of a range of *BioLogica* activities, particularly *Scales* in the Biology class challenged most students including the higher achieving students such as Karl from the Biology class and Phoebe from the Human Biology class in solving pedigree problems.

### 7.9.5 Enjoying may Not Necessarily Mean Learning

Like Mr Anderson in School A, Ms Elliott also thought that enjoyment did not mean learning as she said,

> I know that they enjoyed them [the *BioLogica* activities] (laugh) — any student would enjoy them — and I think the fact that it was interactive and … was something completely different — and they enjoy using computers. Full stop. So to them, it was a good way to actually learn, [and] it's a good learning technique. (Ms Elliott/Postinstructional Interview)

However, she moved on from the motivational aspects to learning for understanding. Unlike Ms Claire and Mrs Dawson in School C, she did not think that her students disliked the Dragons.

> I don't think that they disliked the Dragons. I think that if we're talking about 17-year olds here as well, so initially that was one of my reservations, that perhaps they thought it was a bit unreal, but they seemed to enjoy it, and I think as long as you related it back to the human condition then they could understand why they were actually using the programs. (Ms Elliott/Postinstructional Interview)

However, Ms Elliott thought that some students might not benefit so much as they were unable to transfer from Dragons to humans and from computer to paper-and-pencil tests.

> Students like May, for example, had quite a few problems and yet she did quite well, or she seemed to be coping quite well with the *BioLogica* program. Helena is another student who didn't do particularly well, though in her final test she did [quite well]. (Ms Elliott/Postinstructional Interview)

Again, Ms Elliott's thinking was related to the second function of MERs, that is, to constrain interpretation of phenomena. However, I do not agree with the way she judged the progress of Helena in terms of the test scores. From the online pretest-posttest gains analysis (see Table 7.8 and Figure 7.9), Helena's gain was 30.8% from a low baseline of her pretest score of 15.4%. The online tests for School D should give a good indication of students' progress in genetics reasoning as they had the highest number of two-tier items, including some adapted from the reasoning tasks used in the interviews during the two previous case studies in Schools A and C.

### 7.9.6 Why Some Benefited from *BioLogica* but Not Others?

Ms Elliott did not understand why some students did not improve in their learning when they had the same level of engagement in *BioLogica* activities as other students who did improve. I believe that mindfulness in my explanation grounded in some empirical evidence from several sources may provide this missing link (see section 7.2.2) and learning together with others is also important (see sections 7.5.4 and 7.5.5).

### 7.9.7 Preparation for TEE: *BioLogica* Helped Those who Understood

Ms Elliott predicted that some, but not all students might benefit from their *BioLogica* experiences which would help them to do better in the TEE; her prediction was based on the criterion of whether these students understood what they did during the *BioLogica* activities.

> I would like to think that people like Phoebe and Elisa have understood the concepts really well because of using *BioLogica* and then being able to transfer that information over to the human conditions. But at this stage I don't know whether I could say that, I could say yes by using *BioLogica* they're going to get a 5% increase on their genetics section. I just couldn't say that. (Ms Elliott/Postinstructional Interview)

### 7.9.8 Could have Done Better with More Time

Although Ms Elliott was positive about the way that she worked with me (the researcher) to give feedback to the students by way of the log files, she wished to have more time so that she could have more one-on-one discussion about the actual *BioLogica* activities with the Human Biology students. She believed such additional effective use of time could have helped students to learn better. This aspect is another recurring theme across all the case schools in this study.

The findings about the teacher's and the students' perceptions about the usefulness of *BioLogica* activities are now summarised in Assertion 7.7.

*Assertion 7.7*

*Both the teacher and most students held positive perceptions about their BioLogica experiences but students were more positive than the teacher in their beliefs that such experiences would help their TEE scores; the teacher probably made her prediction in terms of whether students understood what they experienced in BioLogica activities.*

This assertion was based on the interview perceptions of the students and the teacher (see sections 7.8 and 7.9) and indirectly based on the classroom observations and document analyses and interpretations that the students were extrinsically motivated by the belief that the computer activities might help them to do better in the TEE. Computer log files indicated that most students worked through all the *BioLogica* activities that their teacher had arranged for them to do as well some extra ones (see Table A1.7.3 and A.7.4 in Appendix 1).

*Assertion 7.8*

*Most students had conceptual change along the social/affect dimension and epistemological dimension but not along the ontological dimension. This finding was consistent with the experiences of the two classes of Year 12 students for whom genetics was not new and with the teacher's emphasis on problem solving in her teaching.*

The last assertion was generated in response to Research Question 7.6. The Year 12 students in School D did exhibit conceptual change along the social/affective dimension (see motivational outcomes in section 7.3) and epistemological dimension in terms of their improvement in reasoning (see section 7.8). However, the ontological conceptual change—in their gene conceptions as was discussed in section 7.9 (see Table 7.9)—was not obvious. Given that they had already been taught genetics in Year 10 and that they were more mature (17-year-olds) than the Year 10 students (14- or 15-year-olds), their gene conceptions were anticipated to be initially more sophisticated. However, the change was not as obvious as it was for students in Schools A and D. Besides, it appeared that both the teacher and the students were more concerned about preparing for TEE in reasoning and solving problems than about the ontology of the gene.

## 7.10 Summary of Findings

This section summarises nine assertions generated from themes and patterns identified from the multiple sources of data analysed and interpreted in the previous sections. Table 7.11 maps the assertions to relevant research question(s), in response to which the assertions were generated.

Table 7.11

*Summary of Assertions Mapped to Research Questions in Case Study Four*

| Research Question | Assertions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 |
| RQ7.1How does the teacher integrate and implement *BioLogica* in her classroom teaching and learning of genetics to support students with lower prior knowledge in preparing for the Tertiary Entrance Examinations (TEE)? | √ | | | | | | | |
| RQ7.2 What are the teacher's beliefs, referents and actions in the integration and implementation of *BioLogica* in her teaching of genetics? | | √ | | | | | √ | |
| RQ7.3 To what extent does the social/affective dimension of conceptual learning affect the students' engagement in *BioLogica* activities? | | | √ | | | | √ | |
| RQ7.4 What factors affect students' development of genetics reasoning when they interact regularly with the MERs of *BioLogica*? | | | | √ | √ | | | |
| RQ7.5 How do the students learn genetics through their interactions with *BioLogica* in terms of the three functions of the MERs? | | | | | | √ | | |
| RQ7.6 Have the students undergone a three-dimensional conceptual change after the *BioLogica* experience? | | | | | | | | √ |

Assertion 7.1

The teacher integrated and implemented *BioLogica* in her teaching unit of genetics to motivate her students' learning, engender their understanding, and supported their problem solving in their preparation for the-end-of-the year Tertiary Entrance Examinations (TEE).

Assertion 7.2

Although the teacher used some social constructivist ideas as referents for her actions in teaching with multiple representations, she was unable to scaffold her students as she had wished when implementing the *BioLogica* activities because of the constraints of time and the pressure of TEE.

Assertion 7.3

Students had high level of engagement in *BioLogica* activities because initially they were intrinsically motivated by the salient features of the *BioLogica* MERs. Subsequently, they became extrinsically motivated by their belief that the activities help their preparation for the Tertiary Entrance Examinations (TEE).

Assertion 7.4

Students with lower prior knowledge made more improvement in genetics reasoning than did those with higher prior knowledge but not all were able to improve when their level of engagement in the *BioLogica* activities was similar.

Assertion 7.5

Mindful interactions with the MERs, metacognitive strategies, peer learning, and teacher scaffolding within the students' zone of proximal development are important factors for developing genetics reasoning when students had regular engagement in *BioLogica* activities.

Assertion 7.6

*BioLogica* Dragons are familiar constraining representations for interpreting the complex phenomena of human genetics that supports a learner's genetics reasoning. The constraining function of MERs in *BioLogica* Dragons supported some students with lower prior knowledge to make *substantial improvement in their learning in terms of genetics reasoning.*

Assertion 7.7

Both the teacher and most students held positive perceptions about their *BioLogica* experiences but students were more positive than the teacher in their beliefs that such experiences would help their TEE scores; the teacher probably made her prediction in terms of whether students understood what they experienced in *BioLogica* activities.

Assertion 7.8

Most students had conceptual change along the social/affective and epistemological dimensions but not the ontological dimension; this finding was consistent with the experiences of the two classes of Year 12 students for whom genetics was not new and with that the teacher's emphasis on problem solving in her teaching.

## 7.11 Limitations of Case Study Four

Although the findings of the case study in School D were based on strong evidence from several rich sources of data, there were still some limitations when the findings were considered.

First, as the findings from two classes in School D were based on a smaller sample and from Year 12 classes (students aged from 16 to 18), they were not useful for comparing with the learning of Year 10 students (aged from 14-15) although cross-age comparisons make sense in a different way. Second, the interviews were short and conducted only once to suit the very busy students preparing for the TEE. As such, I was not able to explore their gene conceptions and genetics reasoning. Nevertheless, the genetics reasoning tasks converted to two-tier items in the online tests did not allow more in-depth understanding of the students' conception as in a interview situation.

## 7.12 Discussion and Conclusions

The fourth case study in School D was another unique case involving Year 12 students learning with *BioLogica* in an ICT-rich learning environment. The high degree of researcher-teacher collaboration in the case study made it possible to design and implement a learning environment more sensitive to the differing needs of the students within and across the two classes. It is particularly noteworthy that some students with lower prior knowledge made substantial improvement in their genetics reasoning as well as expressing their enjoyment of the *BioLogica* activities.

Not only did Ms Elliott use more activities with higher frequency than in the previous case schools, she also sequenced the selected activities to provide more learning opportunities for the two Year 12 classes, particularly the Human Biology class with lower prior knowledge. Unlike the previous case studies, the small class size and ICT-rich environment and the strong IT support in School D allowed the teacher, students and me to interact in ways that supported student learning. I also did some co-teaching with Ms Elliott when we discussed with students about *BioLogica* activities and online test problems. Such feedback might have helped students develop metacognitive skills while learning to reason and solve problems. Postinstructional interviews indicated that both the teacher and students were generally positive in their perceptions about their experiences of using *BioLogica* activities and the usefulness of these activities for learning genetics. Most students perceived that the teacher' integration and implementation of *BioLogica* activities were useful and supportive for their learning and that these learning experiences would help their preparation for the TEE.

Students in the Human Biology class who started with a low baseline of knowledge of genetics made substantial improvement in their genetics reasoning. Such progress also was echoed in the teacher's test marks. More importantly, the students appeared to have developed some confidence in solving genetics problems. Indeed, their pretest-posttest gains in the researcher's challenging two-tier online tests were compelling and confirming evidence that supported this claim. However, a few students (e.g., Ella and Alina) who did not make progress in their reasoning tests constituted a source of disconfirming evidence that regular interactions with MERs necessarily contributed to learning. Like the previous case studies, the tension arising from the tight time constraints and the research logistics of not interrupting the participants' normal classroom life imposed some limitations on data collection of this case study.

To conclude, I argue that for students to benefit from the *BioLogica* activities, they need to engage in mindful interactions with multiple external representations. Furthermore, teachers using *BioLogica* for teaching genetics need to foster metecognitive strategies and encourage discursive interactions such as collaborative peer learning. The three functions of MERs, namely, to complement, to constrain, and to construct, appear to provide a powerful framework for interpreting how multiple representations should be used to and could support conceptual learning with ICT in science education. The next chapter will be about cross-case analyses of students learning.

# Chapter 8

# Conceptual Learning with Multiple Representations: Cross-case Analyses

> Since they were first recognised 150 years ago, dinosaurs have fascinated the public. Dinosaur books, games and objects are now a huge worldwide market. The film industry has also used dinosaurs as entertainment, often mixing fact with fiction… Dinosaur fossils have been weathering out of the earth for millions of years. In ancient China they were thought to be the remains of dead Dragons and were ground up for medicine… Dragons were believed to have magical powers.
>
> (Natural History Museum, 2002)

## 8.0 Overview

This chapter discuses the analyses of students' conceptual learning of genetics in the classrooms across the case schools where the teachers included in their teaching *BioLogica* or other multimedia. As discussed in Chapter 3, in qualitative research it is more appropriate to use *transferability* in place of *generalisability* (Guba & Lincoln, 1989). However, as Miles and Huberman (1994) put it, "the question [of generalisability] does not go away" (p. 173). Accordingly, a cross-case analysis allows researchers to enhance generalisability or transferability and in this case to deepen the understanding of the generic processes across the cases and the explanations for these processes.

Of the four case studies, Case Study Two in School B was quite different from the other three cases in content and context as reported in Chapter 5. First, Miss Bell, the preservice teacher, taught only briefly in School B as part of her teaching practice. Second, little student data were collected from School B. As such, the cross-case analysis in this chapter focuses mainly on the students' learning outcomes across the other three case studies in Schools A, C and D where the experienced teacher(s) taught genetics with computer-based multiple representations and the research extended over the whole period of teaching the genetics course. Through comparing and contrasting the within-case findings in terms of case-specific assertions in the four results chapters (Chapters 5, 6, 7 and 8), I am trying to identify some common threads that warrant further analyses towards drawing the general conclusions for this study. The complex process of cross-case analysis was guided by some emergent research questions which I will discuss in the next section. The status of students' conceptions of genes or genetics is the major thread in the cross-case analyses in this chapter using Thorley's (1990) categories.

## 8.1 Revisiting and Reformulating Research Questions

To re-examine the conceptual learning of genetics across Schools A, C and D, it is necessary to revisit the three initial research questions related to student learning under Focus 2 described in Chapter 3:

Research Question 4

What are the factors from the social/affective perspective that influence students' interaction with *BioLogica* in their conceptual learning of genetics?

Research Question 5

Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? If so, to what extent and in which types of genetics reasoning?

Research Question 6

What are the students' gene conceptions before and after the lessons that include *BioLogica*?

As the case studies progressed during the research, these research questions were modified and reformulated in each case study to suit the different contents and contexts and some new research questions emerged from the case studies. These specific research questions had guided each case study and the subsequent reporting of the within-case analysis in the four results chapters.

The cross-case analysis in this chapter seeks to construct abstractions across three case schools (Schools A, C and D) and the embedded subunit cases—the classes and the individual students. I therefore reformulate these research questions in light of the major components of the theoretical framework discussed in the literature review chapter (Chapter 2), namely, reasoning in the history of genetics, conceptual change learning and multiple representations. As such, the first two initial research questions are reformulated into one single research question:

Research Question 8.1

How are multiple representations or MERs functions related to intelligibility, plausibility and fruitfulness in students' learning of genetics?

In Chapters 4 and 6, students' conceptual status was analysed in terms of the ontological progression of their mental models of the gene (Venville & Treagust, 1998). However, as the case studies progressed, I gradually found that Thorley's (1990) status analysis categories can provide a more robust analysis of the status of students' conception using a system to categorise a conception being intelligible, intelligible-plausible or intelligible-plausible-fruitful. After I had tried these categories out in analysing Miss Bell's learning and teaching during the Second Case Study in School B (See Chapter 5), I became more confident that Thorley's method of determining conceptual status would be useful for a cross-case analysis of students' conceptual change across Schools A, C and D. As such, I now reformulate the third initial research question into Research Question 8.2 as follows:

Research Question 8.2

What is the status of students' conceptions of genetics after the genetics course that includes computer-based multiple representations?

This research question guides the second part of the cross-case analysis in this chapter about the conceptual status of selected case students. When the status is high, that is, when the conception is found to be intelligible-plausible-fruitful, I then look at how MERs of *BioLogica* or other multimedia (as in School C) might have contributed to the change. When the status is low, I also tried to look for a possible reason. This is also related to the first research question. Data from multiple sources will be used in triangulation in the analysis.

## 8.2 Multiple Representations and Conceptual Change

This section focuses on the how students' conceptual learning of genetics—that included engagement in *BioLogica* activities—can be related to their interaction with the multiple external representations (MERs) in *BioLogica*. The cross-case analysis is based on class-wide data from online tests, log files and classroom observations and teachers' ideas during their interviews. In this section, only three dimensions of conceptual learning, namely, social/affective (motivational), epistemological and ontological dimensions, are considered in the following analyses.

### 8.2.1 Complementary Information/Processes and Motivation

In retrospect, all the teachers in these three case schools—Mr Anderson, Ms Claire, Mrs Dawson and Ms Elliott—had the common expectation that *BioLogica* (or the way genetics is presented with MERs) would motivate their students in their learning.

As discussed in the various results chapters, the expectation of teachers differed due to their different beliefs and referents for their actions. In School A, a state school following a rather limited curriculum prescription, Mr Anderson believed that students, although interested in genetics, had difficulties in learning the genetics crosses because some students were not at Piagetian formal operational stage. Hence, the interactive program could motivate learning, speed up teaching and engender understanding. In School C, a private school with a flexible curriculum, Ms Claire and Mrs Dawson appeared to hold the belief of *multiple intelligences* (Gardner, 1993) that students had different learning styles and that teaching should be enacted to cater for their learning needs, particularly in using the laptop computers for classroom learning. For Ms Claire and Mrs Dawson, *BioLogica* was but another interactive multimedia resource for diverse learning styles of the girls who had already been using other online multimedia. In School D, a state senior school, Ms Elliott—who taught two Year 12 classes preparing for the Tertiary Entrance Examinations (TEE)—had slightly different expectations. She intended to motivate the uninterested students with low prior knowledge in the Human Biology class so that they could be better prepared for their TEE. At the same time, she was the only teacher who had spent much time trying out the *BioLogica* program and knew the

MERs better than did the other three teachers. Consequently, she used *BioLogica* activities as an integral part of her teaching despite the tight time constraints because she believed that the interactive computer activities could provide the visual ways (major component of MERs) of helping students to better understand genetics when preparing for their TEE. As discussed in Chapter 7, both intrinsic and extrinsic motivations were displayed by the students.

Rich data from interview and lesson transcripts, online test postings, video images and the log files provided compelling evidence that the salient features of the multiple representations in *BioLogica* activities appeared to be intrinsically motivating to most students in School A and D and many in School C (see Table 8.1). Visualisation appeared to be the most motivating feature (see section 9.1.8 and Figure 9.3).

*Table 8.1*

*Students' Intrinsic Motivations in Using BioLogica across Three Case Schools (based on Tables 4.4, 6.3, and 7.3)*

| Intrinsic Motivations | School A<br>No of Year 10 students [a] (%)<br>(*n* = 24) [b] | School C<br>No of Year 10 students (%)<br>(*n* = 37) | School D [c]<br>No of Year 12 students (%)<br>(*n* = 13) |
|---|---|---|---|
| Curiosity | 13 (42%) | 16 (43%) | 4 (31%) |
| Challenge | 5 (21%) | 1 (3%) | 1 (8%) |
| Control | 4 (17%) | 0 (0%) | 1 (8%) |
| Fantasy | 3 (13%) | 0 (0%) | 5 (38%) |
| Peer support | 6 (25%) | 2 (5%) | 5 (38%) |

[a] Counts of students mentioning the ideas pertaining to intrinsic motivations were based on interviews, online test postings or lesson transcripts; if they were identified in more that one data source for a particular student, he or she was only counted once.

[b] Total number of students in all sources of data.

[c] For School D, no online test data were about perceptions; in the interviews students were explicitly prompted by the interviewer about these motivations.

According to the review in Chapter 2 (section 2.2.8.2), the salient features of the MERs of *BioLogica* constituted the *situational interests* to which students responded differently depending on their own *individual interests* and became motivated. In this study, the intrinsically motivating effects of these situational interests increased the intelligibility of concepts of genetics with which students learnt to reason. As can be seen from Table 8.1, the Year 10 students (aged 14-15) appeared to be more curious about the MERs of *BioLogica* compared to the Year 12 students (aged 16-18). Of the three groups, students in School C appeared to be least intrinsically motivated. As I have discussed in Chapter 6, many girls in School C were more interested in the web-based interactive multimedia on human and molecular genetics. Furthermore, given that the girls in School C each owned a laptop computer, they could have had more experiences using *BioLogica*, if they had been more interested in the program.

In interviews/online tests as well as in the teacher's tests/assignments, most students knew what a gene is. They verbalised their gene conceptions using human examples or represented them in drawings. At the same time, many students talked about how they enjoyed learning genetics because of *BioLogica* or other online multimedia (in School C only). As Hewson and Lemberger (2000) pointed out, the essence of intelligibility can be captured by *representability* such as the use of images, exemplars or language (see Table 2.3). Drawing on the analyses in the results chapters supported by the extensive review of the literature in Chapter 2, I argue here that the first function of MERs (see section 2.3.4.1)—the complementary role of using different information or processes—can be considered as an effective way of raising the intelligibility of students' conceptions of genes for scientific reasoning or genetics reasoning (see section 2.2.6). A concept must first be intelligible to the students before it can be plausible and then fruitful. This will be further explored in the cross-case analysis of the status of the conceptions of selected students from the three case schools in section 8.3. If Ainsworth's (1999) functional taxonomy of MERs is of any relevance here, *BioLogica* appeared to have provided motivating complementary information or processes that were useful in making the difficult concepts of genetics initially intelligible to the students.

### 8.2.2 Constraining Interpretations/Misinterpretations and Plausibility

In all the four case studies, the two-tier items in the online tests used the six types of genetics reasoning (Hickey & Kindfield, 1999) to probe students' understanding in genetics. Each type of genetics reasoning consists of a domain-general dimension and a domain-specific dimension (see Table 3.1). This section compares and contrasts the genetics reasoning of students across the three case schools and attempts to interpret the differences in terms of the way in which multiple representations were used, the classroom discourse and other contextual factors. A summary of the statistics of number of students taking the online tests across the four case schools is shown in Table 8.2.

Table 8.2

*Summary Statistics of All Participants in Online Pretests and Posttests*

| Classroom Sites | Number of Students who Did | | |
|---|---|---|---|
| | Both Pretest and Posttest[a] | Pretest | Posttest |
| School A (Year 10) | 20 | 22 | 23 |
| School B (Year 10) | 0 | 0 | 3[b] |
| School C / Class1 (Year 10) | 14 | 21 | 16 |
| School C / Class2 (Year 10) | 17 | 21 | 20 |
| School D / Biology Class (Year 12) | 8 | 10 | 8 |
| School D/ Human Biology Class (Year 12) | 6 | 6 | 6 |
| Total | 65 | 80 | 76 |

[a] The online tests were local versions.

[b] An online test similar to the posttest done by three students at home.

Although the interpretive, case-based approach allows the use of some quantitative analyses, close scrutiny of the case database reveals that the number of common two-tier items was small (see Table 3.2), the samples of students taking the tests were not random and the sample sizes were small. As such, it is not appropriate to use statistics in analysing item reliability. Instead I used some descriptive statistics—such as the percentages of students who had both tiers correct in the two-tier item(s) of a particular reasoning type—to display the results for comparing and contrasting the student performance across the cases and the types of genetics reasoning.

The cross-case contrasts and comparisons of the preinstructional-postinstructional genetics reasoning were done on the basis of the five common parallel two-tier items in the online tests across the three schools (Schools A, C and D). Such analysis also looks at the how students fared in four different types of genetics reasoning by simply comparing the percentage of students with correct responses on the two-tier items in different types of reasoning (see Table 3.1).

### *8.2.2.1 Genetics Reasoning: Comparison of Year 10 and Year 12 students*

When I was conducting the research in School D, I had the intuitive impression that the prior knowledge of the Year 12 students appeared to be rather low, especially in the Human Biology class. This section attempts to compare the preinstructional-postinstructional improvement in the genetics reasoning across the three schools: School A (one class Year 10), School C (two classes of Year 10) and School D (two Year 12 classes). Figure 8.1 shows the comparison based on the five two-tier parallel items common to Schools A, C and D.

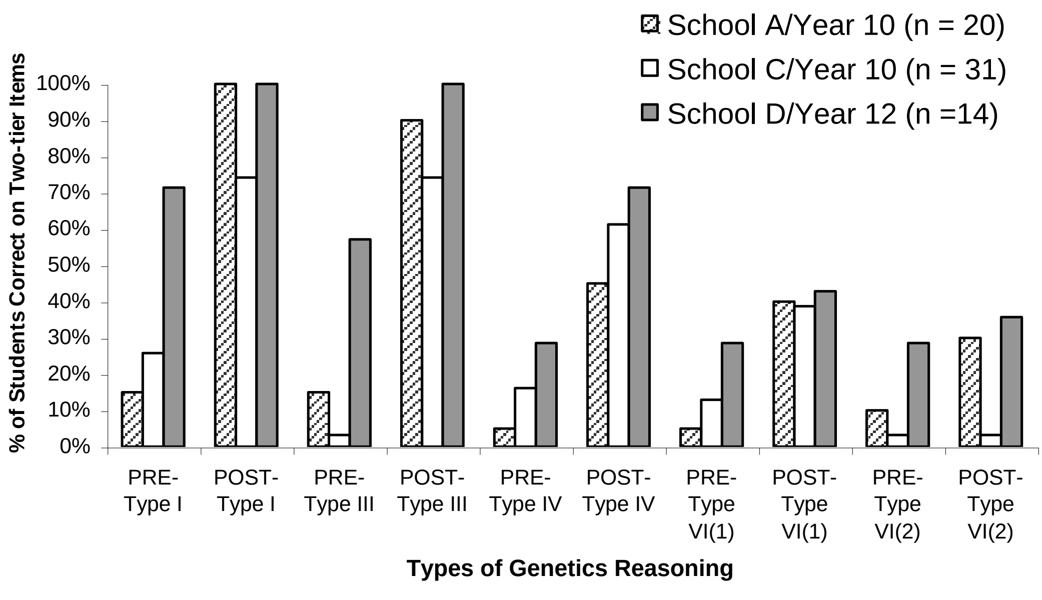



*Figure 8.1* Comparison of preinstructional-postinstructional improvement in genetics reasoning across Schools A, C and D.

When the results across three schools are displayed in Figure 8.1, in addition to the slight differences between the two groups of Year 10 students in Schools A and C, the differences between the Year 10 and Year 12 students are obvious. Not only did the Year 12 students have better prior knowledge of genetics reasoning in all four types of genetics reasoning but they also made greater improvement in all types of reasoning. From the conceptual change perspective, genetics reasoning is related to the plausibility of the students' conception of genetics. Thorley's status elements for plausibility are mainly about the consistency and causal mechanism (see Table 2.3) which are closely related to demand of the two-tier items about genetics reasoning.

#### *8.2.2.2 Why Laptops Didn't Make a Difference?*

As already discussed in section 6.4.2.2, the comparison of the online tests results of School C and those of School A on the mean scores of the six common two-tier items (the additional item common to Schools A and C was about identical twins) indicated that students' improvement in genetics reasoning across the two schools were quite similar (also see Figure 6.5). School C did not outperform School A. We would have predicted that laptops made a difference because students had unlimited access to *BioLogica* and other online multimedia.

To build up some logical chains of evidence (Miles & Huberman, 1994) for some possible explanations, we need to revisit the within-case analyses in Chapters 4 and 6. First, based on the interviews and classroom observations, it appeared that Ms Claire and Mrs Dawson used interactive multimedia including *BioLogica* to engender students' understanding of the molecular nature of the gene for studying DNA and genetic engineering which constituted the last one third of the biology unit in Year 10 science. As such, their intention to use the MERs was to provide students with complementary information and processes rather than for constraining their interpretations in solving genetics problems. The less interactive online multimedia which students used probably served to complement more than to constrain. In contrast, Mr Anderson did see the usefulness of *BioLogica* in constraining students' interpretations in solving problems although eventually he did not believe that students actually learnt from *BioLogica* other than enjoying the activities. Second, according to School C students' online self-reports about their usage of *BioLogica* activities (see Table 6.1) indicated that students were not engaged in *BioLogica* activities as often as did the students in Schools A and D. However, as we shall see in the next section, School C students had developed more sophisticated gene conceptions than those of students in School A.

#### *8.2.2.3 Understanding of Meiosis*

Another pattern that warrants discussion here is that the students in School C did not have any improvement in genetics reasoning item Type VI (2) (see Figure 8.1) or the *black-box problem* about meiosis (see Appendix 2, Figure A2.4.6) whereas both the Year 10 counterparts in School A and the Year 12 students in School D made substantial improvements. The Year 10 students in School A had slightly more prior knowledge about meiosis than the Year 10 students in School C.

Data from multiple sources already discussed in the various results chapters showed that many students and teachers singled out the role of visualisation provided by *BioLogica* as promoting understanding of the complicated process of meiosis. The literature review indicated that meiosis is among the most difficult and important parts for understanding genetics (Kindfield, 1994) (see Chapter 2).

To end this section, let us revisit Ainsworth's (1999) functional taxonomy of MERs. As reviewed in Chapter 2, the MERs can support learning by constraining interpretations (or misinterpretation) of scientific phenomena. Based on the preceding supporting evidence, I argue that School C students used the MERs for complementary information and processes more than as constraints for reasoning in genetics. However, as we shall see in the next section, because of the unlimited access to the MERs of *BioLogica* and other online interactive multimedia, the girls in School C did develop better gene conceptions and constructed deeper understanding of the molecular nature of the gene compared to the students in Schools A and C.

### 8.2.3 Constructing Understanding and Ontological Conceptual Change

This section draws on the within-case analysis to compare the students' ontological change (Chi, 1992; Chi et al., 1994) that took place (see Chapter 2) in their gene conceptions. Using the data from Chapter 4 (Table 4.5), Chapter 6 (Figure 6.8) and

Chapter 7 (Table 7.8), I merged and tabulated the data in Table 8.3 for comparing the preinstructional-postinstructional changes in the students' conceptions of the gene across the three schools.

Table 8.3

*Gene Conceptions across Schools A, C and D*

| Category | Gene Conceptions | School A (Year 10) | | School C (Year 10) | | School D (Year 12) | |
|---|---|---|---|---|---|---|---|
| | | Pretest (*n*=21) | Posttest (*n* =23) | Pretest (*n*=42) | Posttest (*n*=37) | Pretest (*n* =16) | Posttest (*n*=15) |
| 1 | A gene is from parents/grandparents | 11(52) | 15(65) | 25 (61) | 15(41) | 6 (38) | 5 (33) |
| 2 | A gene determines a trait / characteristic | 5 (24) | 21(91) | 22 (54) | 16(43) | 10 (63) | 9 (60) |
| 4 | A gene is /part of a chromosome | 3 (14) | 9(39) | 0 (0) | 16(43) | 3 (19) | 5 (33) |
| 5 | A gene is / part of DNA | 2 (10) | 1 (4) | 14 (34) | 14(38) | 4 (25) | 2 (13) |
| 6 | A gene is information[a] | 2 (10) | 1 (4) | 1 (2) | 3 (8) | 1 (6) | 3 (20) |

[a] By subsuming three categories in Table 7.9—13. A gene contains genetic code, 15. A gene contains instruction and 18. Productive instruction for making protein.

Only five major categories of gene conceptions are included for contrasts and comparisons. It must be noted that such analysis should be viewed from a case-oriented approach more than from a variable-oriented approach. The qualitative tradition does not consider the five common categories of gene conceptions as variables but rather some patterns across the cases. As in the previous sections in this chapter, I am building up some logical chain of evidence and to look for possible explanations for any differences identified.

#### *8.2.3.1 Case-specific Differences and Similarities in Gene Conceptions*

Each school or group of students showed one or two unique case-specific patterns in their conceptions of the gene for which I have some possible explanations based on within-case analysis and cross-case analysis.

For School A, the case-specific pattern is that the students showed substantial change on category 2 or from an inactive-particle gene (24%) to an active-particle gene (91%) compared to students of the other two schools. As discussed in Chapter

4, data from both online tests and interviews indicated that the Year 10 students started their study of genetics with a very limited prior knowledge of genetics. Their teacher's emphasis on meiosis and genetic crosses in the teaching, together with their engagement in three *BioLogica* activities, enabled the students to develop better understanding of the genotype-phenotype relationship. To them, the human genes (genotype) control the characteristics (phenotypes) just like those in the Dragons. However, those students did not know what the gene does in controlling the characteristic. Even Matthew, the high-achiever, was unable to explain this in the postinstructional interview (see section 4.4.3.2). Further, Mr Anderson did not teach about the DNA function in protein synthesis. Nor did he think that the *BioLogica* activities about the DNA Level such as *Mutations* were suitable for Year 10 students (see section 4.5.4).

In School C, there were two case-specific patterns about the students' gene conceptions. First, students did not conceptualise a gene as part of a chromosome (category 4) until after instruction but they had better knowledge of the gene being part of the DNA (category 5) than had the other two groups of students. The time-ordered information, my journals and lesson transcripts on 24 May, are all useful for building up some possible explanations for these patterns. Students in both classes took the pretest before their teachers taught mitosis and meiosis (see Appendix 1, Table A1.6.1). However, the teachers had already taught about *Cell Function and Structure* that included the cell nucleus (see Appendix 3, Document A3.6.1). Given that the teachers highlighted DNA structure and functions in the biology unit, these teachers might not have explained clearly how genes are related to chromosomes in Mendelian genetics. As classroom observations started later, no observation data were available to support my conjecture here.

In School D, the Year 12 student (aged 16 to 18) had much better prior knowledge about the gene in all categories except the last one compared to students in Schools A and C. These were the expected results.

The common pattern across the cases is that very few students in all the three groups mentioned about the gene being information which is related to the students' ontology of the gene being matter or process. To understand the students' ontological progression in their gene conceptions (Venville & Treagust, 1998), I compared students' genetics reasoning (Type V) about the sophisticated gene across School C and D based on one common Type V two-tier item (this item was not in the posttest for School A) (see Appendix 2, Figure A2.4.5). Figure 8.2 indicates that 29% of Year 12 students (*n* = 14) had used this type of reasoning correctly before instruction but the percentage of students who did so remained almost unchanged after instruction. With rather low pretest results, School C students made substantial improvement (3% to 10%) (see Figure 8.2). The unchanged results for School D, as indicated by Figure 8.2, can be explained by the possible ceiling effect (see section 7.8.1)

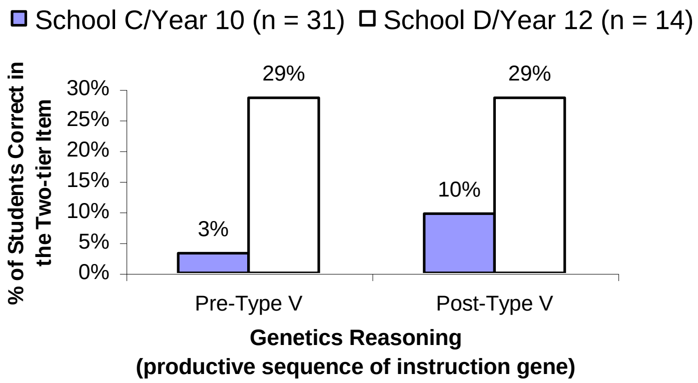



*Figure 8.2* Comparison of preinstructional-postinstructional improvement in genetics reasoning Type V across Schools C and D.

### *8.2.3.2 Ontological Conceptual Change*

Overall, the students' conceptions of the gene were still not sophisticated. School A students appeared to have the most obvious ontological conceptual change within the categories of matter, i.e., from an inactive-particle gene to an active particle gene. The students of Schools C and D held the conception of an active-particle gene before instruction. The Year 12 students in School D had already held rather sophisticated conceptions of the gene before instruction started. Very few students displayed ontological conceptual change across categories after instruction. To construct deeper understanding, one of Ainsworth's (1999) functions of MERs, students need to conceptualise the gene as a particle on the chromosome or segment of DNA as well as a process whereby protein synthesis is initiated and controlled. As the cross-case analyses here indicate, School C was working towards this objective. At a time when there are heated debates on the controversial issues such as genetically modified foods or cloning, Year 10 students in Australian schools need to learn more about the molecular nature of the gene as did those in School C.

## 8.3 Conceptual Status of Nine Interviewees

Hewson and Hewson (1992) explained clearly that the status of a person's conception is the extent to which the conception meets the conditions of intelligibility, plausibility and fruitfulness and that the more conditions that a conception meets, the higher will be its status[29]. This section analyses interview transcripts or online test postings of students across the three schools for interpreting the status of their conceptions using Thorley's (1990) status analysis categories analysis (see Table 2.3) and partly based on Hewson and Lemberger's (2000) method.

I interviewed 26 target students—on the basis of their pretest scores in Schools A and C and all students in School D who agreed to be interviewed (13 out of 17 students) (see Table 8.4). The students in each school were ordered by the pretest-posttest gains in their scores on the local online tests. According to Hewson and Hewson (1992), the interviews were "nontechnical" (p. 63) in that both interviewer and interviewees did not use any technical terms about the conceptual change model (CCM) in the interview.

In ordering the case students in the matrix displayed in Table 8.4, I used the local online test marks instead of the global online test marks based on the five common items as in the comparison display shown in Figure 8.1. The local online tests were progressively improved and expanded to suit the case-specific context so that they can better reflect the learning outcomes in keeping with the context of the case school. This cross-analysis strategy is to keep "the local configuration of variables intact" (Miles & Huberman, 1994, p. 237).

[29] I was in the audience when Hewson and Hewson presented a seminar in our education centre on 8 August 2002 about the conceptual status and had the opportunity to talk to them after the seminar.

Table 8.4

*Case-ordered Matrix based on Local Pretest-Posttest Gains*

| Student | Year | Age | School | Class[a] | Pretest[b] (%) | Posttest [b] (%) | Pretest-posttest Gain (%) |
|---|---|---|---|---|---|---|---|
| Matthew | 10 | 15 | A | - | 33 | 100 | +67 |
| Eric | 10 | 15 | A | - | 17 | 33 | +16 |
| Laurie | 10 | 15 | A | - | 33 | 33 | 0 |
| Nelly | 10 | 15 | A | - | 50 | 33 | -17 |
| Andrea | 10 | 15 | C | 1 | 29 | 87 | +58 |
| Erika [c] | 10 | 14 | C | 1 | 0 | 57 | +57 |
| Terri | 10 | 14 | C | 2 | 0 | 57 | +57 |
| Cindy | 10 | 15 | C | 1 | 14 | 57 | +43 |
| Isabelle | 10 | 15 | C | 1 | 29 | 71 | +42 |
| Rita | 10 | 15 | C | 2 | 0 | 29 | +29 |
| Elaine | 10 | 15 | C | 2 | 29 | 57 | +28 |
| Anne | 10 | 14 | C | 2 | 29 | 57 | +28 |
| Etta [c] | 10 | 14 | C | 2 | 0 | 14 | +14 |
| Audrey | 12 | 17 | D | HB | 15 | 62 | +47 |
| Elisa | 12 | 17 | D | HB | 31 | 77 | +46 |
| Paul | 12 | 17 | D | HB | 23 | 62 | +39 |
| Helena | 12 | 16 | D | HB | 15 | 46 | +31 |
| Phoebe | 12 | 17 | D | HB | 69 | 85 | +16 |
| Bob | 12 | 17 | D | B | 77 | 85 | +8 |
| Hilary | 12 | 17 | D | B | 54 | 62 | +8 |
| Margaret | 12 | 17 | D | B | 46 | 69 | +5 |
| Alina | 12 | 17 | D | HB | 31 | 31 | 0 |
| John | 12 | 17 | D | B | 39 | 39 | 0 |
| Karl | 12 | 17 | D | B | 100 | 100 | 0 |
| Ella | 12 | 18 | D | HB | 54 | 54 | 0 |
| Juvena | 12 | 17 | D | B | 53 | 46 | -7 |

[a] 1 = Ms Claire's class ; 2 = Mrs Dawson's class ; B = Biology class ; HB = Human Biology class.

[b] The scores were based on the local pretests and posttests (parallel items).

[c] Etta did not turn up for the postinstructional interview.

From this case-ordered matrix, I further short-listed nine students for conceptual status analysis—Matthew and Eric (School A); Andrea, Terri and Elaine (School C); and Audrey, Helena, Phoebe and John (School D)—based on their low pretest scores, substantial pretest-posttest gains, and complete interview data. These students represented both genders (six girls and three boys) and the ability range in each of the five classrooms across Schools A, C and D. I chose more students in those classrooms from which I expected to obtain more findings to address the emergent research questions. As for School D, there were two students—Alina (Human Biology class) and John (Biology Class)—who did not make any progress. Classroom observations (2 September 2002) indicated Alina kept talking with another boy while she was doing the online posttest. On the next day, Alina obtained 78% in Ms Elliott's genetics test—two of the highest achievers in the class (see Appendix 1, Table A1.7.5). John's score in the Ms Elliott's test was 56%—the lowest in his Biology class (see Appendix 1, Table A1.7.5). As such, I selected John as a case student with lower prior knowledge who did not make improvement.

This selection is underpinned by purposeful or theoretical sampling logic (Patton, 1990) (see section 3.6.2.1). The data collected for determining status in School D is slightly different from Schools A and C because the 13 students were only interviewed once in a short postinstructional interview with no reasoning tasks. As suggested by Hewson and Hewson (1992), I interpreted interviewees' status of their conceptions from the verbal or written data—both the representations of their conceptions and the comments about their conceptions, i.e., comments which are "metaconceptual" (Thorley, 1990, p. 116). For students in School D, where there were not enough interview data for determining status, I also analysed their responses to online test open-ended questionnaire items and to questions in *BioLogica* activities captured by log files of which a complete set was collected.

### 8.3.1 Matthew: A Fruitful Reasoner with Power and Promise

Matthew, the high achiever in School A, had the largest pretest-posttest gain (+67%) among all the 26 interviewees. Genes were initially intelligible and plausible to him in the first interview as indicated by the symbols he used and the way he explained inheritance in terms of meiosis and fertilisation (see Figure 8.3 and Table 8.5).

Table 8.5

*Status Analysis of Matthew's Gene Conception*

| Student (School) | Quotes (Interviewer's Question in bracket)/Episodes | | Conception Status Elements |
|---|---|---|---|
| | Preinstructional Interview | Postinstructional Interview | |
| Matthew (A) | "In the chromosomes there are hundreds and thousands of these genes ...and they each … might be dominant or recessive.. determine the different characteristics" | | Intelligibility (+LANGUAGE; +IMAGE) |
| | "Well it [a gene] might control the development of the cells and make them specialised …" | | Plausibility (+ REAL MECHANISM; + P ANALOGY) |
| | "Well, the father may have had something like that [He wrote symbols on the task sheet] and the mother would have been like that as well and when the cells were going through meiosis it would have had a bunch of the cells that had just one big A and another bunch that just had small a. So when Pierre's egg was fertilized, Pierre might have got the big A and the small a and Marianne might have got just two small as "(see Figure 8.3) | | Plausibility (+ P ANALOGY) |
| | | "Umm (long pause) I am still a little bit unclear about that but ...[g]enes control development in a cells or any cells … | Plausibility (– REAL MECHANISM) |
| | | "They will just give different signals out to where cells are developing..." ("How do genes affect development?") "I'm not sure" | |
| | | Could solve the sex-linked problem by resolving the anomaly and explaining.. | Plausibility (+ REAL MECHANISM) |
| | | ("…genetics you've learnt is useful to you?") | |
| | | "Yeah, um… it helped me to understand how children get certain thing from their parents" | Fruitfulness (+POWER) |
| | | "My opinions have changed because I [now] know what's involved with GM [food] and stuff like that." | Fruitfulness (+ PROMISE) |

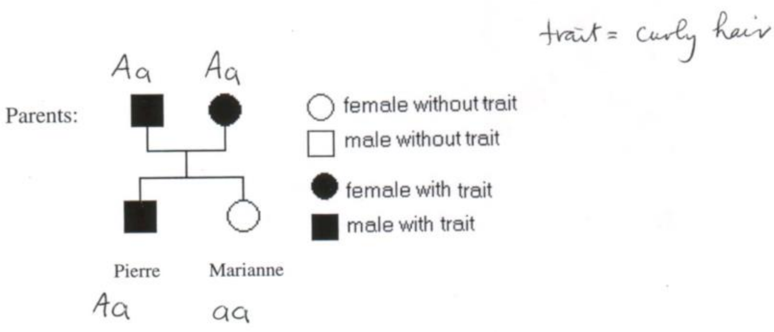



*Figure 8.3* Matthew's genotype symbols.

As discussed earlier in Chapter 4, status analysis according to Venville and Treagust's framework indicted that his conception was not fruitful even after instruction. Using Thorley's categories, Matthew's gene conception can be categorised as IPF although he could not clearly explain the *signals* in scientific language to satisfy the definition of a Venville and Treagust's sophisticated gene (see Table 4.6). His inability to describe the function of DNA or gene was consistent with his classroom learning. His teacher, Mr Anderson, did not use these linguistic labels such as protein synthesis or messenger RNA in the classroom as did Ms Claire and Mrs Dawson in School C. Nor were these terms found in the three *BioLogica* activities used in School A. Nonetheless, a number of segments of Matthew's postinstructional interview can be mapped to Thorley's (1990) fruitfulness status elements of POWER and PROMISE (see Table 8.5).

### 8.3.2 Eric: A Reasoner who Knew *What* but Not *How* and *Why*

For Eric from School A, the genes were intelligible to him in the first interview according to the way he represented the gene by language and image of DNA (see Figure 8.4) as referred in Table 8.5.

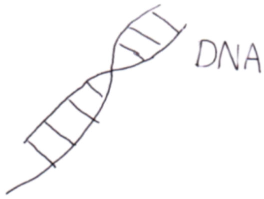



*Figure 8.4* Eric's DNA drawing.

However, Eric's conception of the gene was not plausible before instruction as he viewed genes as entities which, when "they're put together", they will make a new individual (see Table 8.6). Looking at genes and individuals as belonging to the same ontological categories lowers the plausibility status as this is not consistent with other status elements. As already discussed in Chapter 4, using Venville and Treagust's (1998) framework, Eric's conception status was just intelligible but not plausible even after instruction (see Table 4.6) However, when an analysis is repeated here with Thorley's (1990) status analysis categories, there was enough evidence from the interview transcript segments to support my claim that Eric held an intelligible-plausible (or partly plausible) conception of a gene or IP after instruction.

Table 8.6

*Status Analysis of Eric's Gene Conception*

| Student (School) | Quotes (Interviewer's Question in bracket)/Episodes | | Conception Status Elements |
|---|---|---|---|
| | Preinstructional Interview | Postinstructional Interview | |
| Eric (A) | "…your father has certain genes and so does your mum…they're put together so it makes Pierre or Marianne…"<br><br>"Yeah? I'm not sure if it's two big rs or um…So you need two big R's." | | Intelligibility (+EXEMPLAR; + LANGUAGE)<br><br>Plausibility (−METAPHYSICS; − OTHER KNOWLEDGE) |
| | | "DNA is made up of genes and chromosomes are made up into genes" (see Figure 8.4)<br><br>Could identify and explain simple dominance inheritance pattern but not sex-linked inheritance [a]. | Intelligibility (+IMAGE; +LANGUAGE)<br><br>Plausibility (+ REAL MECHANISM; − OTHER KNOWLEDGE) |

[a] See Appendix 3, Document A3.4.3 for the Genetics Reasoning Task in the Postinstructional Interview.

### 8.3.3 Terri: A Reasoner who Needs More Confidence

Next, Terri of School C had made substantial pretest-posttest gain (+57%) in genetics reasoning (+57%). While the gene is intelligible to her as she could represent the gene as something from the parents that determine characteristics, her conception was not plausible before instruction and was only partly plausible after instruction.

Terri used some familiar human examples to illustrate the gene but she did not appear to understand the new entities associated with the gene concept. The dialogue in the preinstructional interview in Table 8.7 portrays how she grappled with the symbols in explaining the phenotype-genotype relationship. Even with repeated prompts from the interviewer, she still did not seem to feel confident in deciding what genotypes Marianne should have, given that she was not a tongue-roller (Type III genetics reasoning). Nor could Terri confidently decide the parents' genotype (Type IV genetics reasoning). Her status of conception before instruction was thus intelligent but not plausible (see Table 8.7 for the status elements).

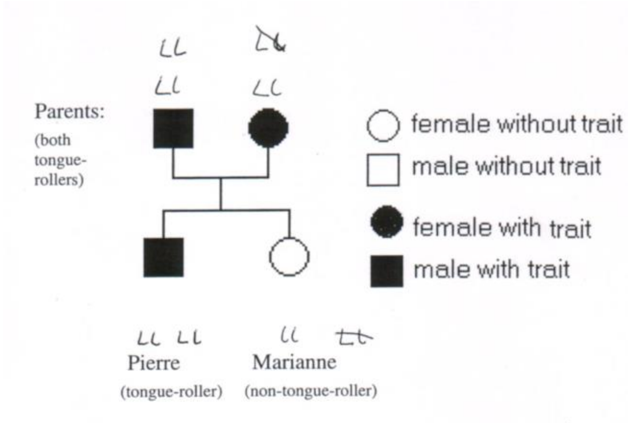



*Figure 8.5* Terri's genotype symbols.

In the postinstructional interview, Terri's gene conception was still not sophisticated because she could not explain clearly how genes or DNA are related to protein synthesis (see Table 8.7). Terri also was unable to display a clear understanding of genotype-phenotype relationships, particularly Types III and IV reasoning in the interview task (see Table 8.7 and Figure 8.6), although in the online posttest she was correct in the two-tier items in both Types III and IV.

Table 8.7

*Status Analysis of Terri's Gene Conception*

| Student (School/ Class) | Quotes (Interviewer's Question in bracket)/Episodes | | Conception Status Elements |
|---|---|---|---|
| | Preinstructional Interview | Postinstructional Interviews | |
| Terri (C/2) | "They [Genes] 're like things that you get from your parents…like … they can determine like whether you're going to have like blue eyes or brown eyes or what colour hair…something like that."<br>(" Marianne has two small ls. Is that OK?")<br>"Um. Well, maybe, she could have one L, and a small l"<br>("Mm. But she can't roll her tongue.")<br>"Oh OK, Yeah. So she couldn't have that." (see Figure 8.5). | | Intelligibility (+LANGUAGE; +EXEMPLAR)<br>Plausibility (– OTHER KNOWLEDGE; – REAL MECHANISM) |
| | | ("What do genes do to bring about the characteristic?)<br>"Like protein synthesis..."<br>("What do you mean by protein synthesis?")<br>"They're like little genetic codes."<br>("Coding for what?")<br>"Nitrogen bases. For the double helix…" | Plausibility (+METAPHYSICS)<br>Plausibility (– P ANALOGY) |
| | | ("OK So now, how do you explain Jane's genotype")<br>Uh huh. Well um, … her parents could be little g or big G little g, or they could be little g big G, little g. And um, so you have that there. And because it's recessive, um, she has a big G and a little g (see Figure 8.6) | Intelligibility (+LANGUAGE)<br>Plausibility (– REAL MECHANISM) |

Terri appeared to know the linguistic labels of the new entities of genetics without fully understanding their relationships and she believed the conceptions to be true. For example, she might believe that DNA controls protein synthesis but could not explain how. As her postinstructional conception was only slightly plausible, I do not analyse some segments of the last part of the interviews for considering the fruitfulness status elements. One's conception must first be intelligible-plausible before it can be fruitful (Hewson & Hewson, 1992). Terri did not have the confidence in articulating her constructed entities because she did not find all her arguments plausible.

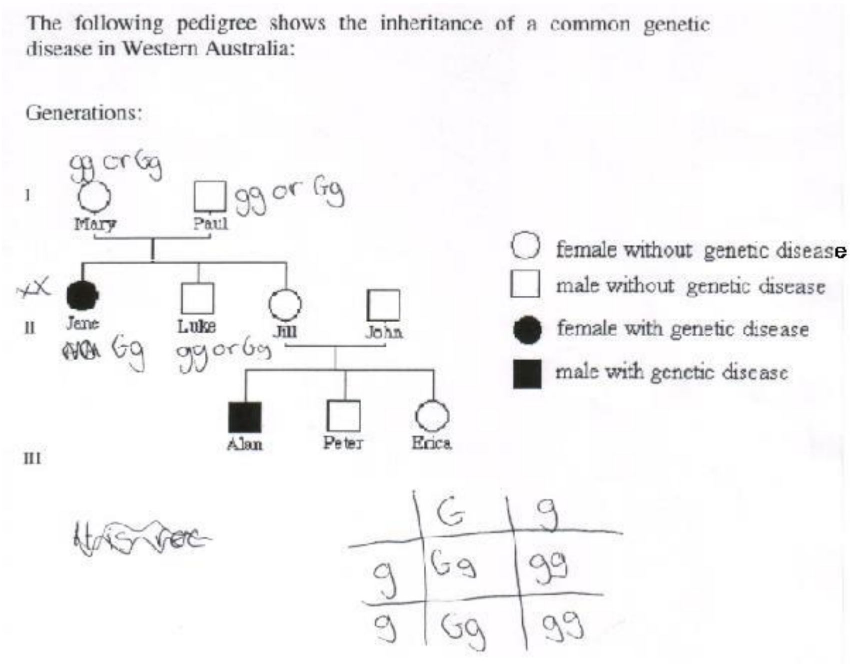



*Figure 8.6* Terri's written work in the postinstructional interview.

### 8.3.4 Andrea: A Fruitful Reasoner with Sophistication and Promise

As reported in Chapter 6, Andrea's conception was found to have an IPF status based on multiple sources of data using Venville and Treagust's (1998) sophistication of the gene as a bench mark for fruitfulness. It would be interesting, too, to see if the same status is obtained with Thorley's (1990) framework.

As can be seen from the analysis in Table 8.8, Andrea's conception is categorised as intelligible-plausible before instruction and intelligible-plausible-fruitful after instruction using either Venville and Treagust's or Thorley's framework.

Table 8.8

*Status Analysis of Andrea's Gene Conception*

| Student (School/ Class) | Quotes (Interviewer's Question in bracket)/Episodes | | Conception Status Elements |
|---|---|---|---|
| | Preinstructional Interview | Postinstructional Interview | |
| Andrea (C/1) | ("Explain… how the genes get passed on from the parents to Pierre and Marianne") | | |
| | "Um, during meiosis the chromosomes from each parent mix together, and the sperm fertilises with (sic) the egg.., it forms a new human" * | | Intelligibility (+LANGUAGE; +IMAGE) |
| | "A gene, um, I think it's like, the plans for your characteristics and tells what each cell should do and stuff." | | Intelligibility (+ I ANALOGY) |
| | ("Tongue-rolling is dominant. So if a girl has two genes, big R and small r, would the girl roll her tongue?" | | |
| | "Yeah. Yes? Don't really know because we haven't really learnt that before…" | | Plausibility (– REAL MECHANISM; – PAST EXPERIENCE) |
| | | "Um. Well, genes … made up of the genetic code in the DNA, which tells the body to make proteins, and um, um they just carry the information which tells the body how it should work and stuff and how it should develop." | Plausibility (+ METAPHYSICS; +REAL MECHANISM; + P ANLAOGY) |
| | | In the reasoning task, she managed to resolve the anomaly to rule out the possibility of the genetic disorder being sex-linked with prompts from interviewer but could not explain exactly why. | Fruitfulness (– POWER) |
| | | "Ah. We understand much more about [this], because they're talking about genes, and you know what genes are now. Like, 'cause they're talking about DNA and everything so we know now why" (about a newspaper clipping). | Fruitfulness (+ POWER; + PROMISE) |
| | | In the third interview, she could confidently use messenger RNA to explain the mechanism of protein synthesis. | Fruitfulness (+ POWER) |

### 8.3.5 Elaine: An Eloquent and Plausible Reasoner

Elaine of School C was one of the most eloquent interviewees who endeavoured to describe and explain the gene in response to the interviewer's questions and to reason with what she knew in the interview tasks. Table 8.9 shows the status analysis of her conception.

Table 8.9

*Status Analysis of Elaine's Gene Conception*

| Student (School/ Class) | Quotes (Interviewer's Question in bracket)/Episodes | | Conception Status Elements |
|---|---|---|---|
| | Preinstructional Interview | Postinstructional Interview | |
| Elaine (C/2) | "It [A gene] can be a physical feature or, it can be a um, like, not a personality but like a um, a, like a it gets passed though families and generations and thing like that…" | | Intelligibility (+LANGUAGE; +IMAGE) |
| | "I don't know, are they [genes] like cells or, or what? I don't really know that much about them because I haven't really learnt anything." | | Plausibility (– METAPHYSICS; – OTHER KNOWLEDGE) |
| | | "Well I can't explain it [a gene]." | Plausibility (–METAPHYSICS) |
| | | "Um, like, another word for gene is allele, no? Or, sort of like another- okay... Um. I don't know really how to explain it. It's sort of like a chromosome or DNA…" | Plausibility (–REAL MECHANISM) |
| | | In the reasoning task, she could explain the autosomal inheritance pattern but not the sex-linked one. | Plausibility (+REAL MECHANISM) |

As can be seen in Table 8.9, that Elaine's conception progressed from merely intelligible to intelligible and fruitful after instruction. Like most of the girls in School C, she did not know a great deal about sex-linked inheritance. This is consistent with the teachers' teaching in the classroom as indicated by the observational data. For example, none of the girls in School C knew how to represent with symbols for genotypes involving the X and Y chromosomes in their explanation during the postinstructional interviews as did students in School A.

### 8.3.6 Audrey: A Mediocre but Fruitful Reasoner

As there was only one interview in School D after instruction, no questions on gene conceptions were asked. Nor were there any reasoning tasks. The interview focused on the Year 12 students' perceptions and comments on their learning experiences. Students' metaconceptual comments, as explained in earlier in this chapter, were useful for determining status. Other sources of data were also used (see Table 8.10).

Table 8.10

*Status Analysis of Audrey's Gene Conception*

| Student (School/ Class) | Postinstructional Interview: Quotes (Interviewer's Question in bracket)/Episodes | Online tests (Pretest or Posttest) / Log file (LF: name of *BioLogica* activity / Date) | Conception Status Elements |
|---|---|---|---|
| Audrey (D/Human Biology) | "In the classroom that I didn't understand … the sex linked and the autosome. That's the only thing that I found hard in genetics." | | Plausibility (–EPISTEMOLOGY) |
| | "I liked it with the Dragons. Easier to understand." | | Plausibility (+P ANALOGY) |
| | "Yeah it [*BioLogica*] helped a lot. I didn't know anything about genetics. This is the first time that I've done it. And, I learnt a lot from the computer, the program [*BioLogica*]. | | Plausibility (+ EPISTEMOLGY) |
| | | ("Explain your understanding of why you got so many more horned babies than hornless ones in the space below.") "There were so many more horned babies than hornless ones as horns were dominant and no horns was recessive." (LF: *BioLogica* activity *Inheritance*/5 August 02) | Plausibility (+ REAL MECHANISM) |
| | "I don't know whether we'd use it [genetics] again but at least we understand, like where we got our eye colour from and stuff like that." | | Fruitfulness (+ POWER; +PROMISE) |

As Table 8.10 shows, Audrey who had the highest pretest-posttest gain (+47%) in the two-tier reasoning tests, started with a very low pretest score (15%). It must be noted that the online tests in School D were improved to include two items in each type of genetics reasoning and that some of the interview tasks were also incorporated in the tests as two-tier items. Using Thorley's framework, Audrey's gain of +47% in the online tests conferred on her POWER. In the interview, she displayed a sense of confidence in her learning and attributed her understanding to the regular engagement in *BioLogica* activities. She completed all the seven *BioLogica* activities required by Ms Elliott. The nine log files (see Appendix 1, Table A1.7.3) provided detailed records of how she worked seriously through all the seven activities. According to Thorley's categories, her gene conception was probably not intelligible before instruction as she said, "I didn't know anything about genetics. This is the first time that I've done it." (see Table 8.10). However, she scored 15% on the 12 two-tier items for the online pretest but the records showed that she was 50% correct in Types I and II reasoning. As such, her preinstructional conception should be intelligible but not plausible. Her pretest-posttest improvement in genetics reasoning was substantial. Although no reasoning questions were asked in the interview, analysis of her *Mutations* log file and her Type V reasoning items indicated her understanding of the ontological status of the gene. Therefore, her conception was still IPF and her ontological progression of mental models was from intelligible (I) to intelligible-plausible-fruitful IPF (Venville & Treagust, 1998).

### 8.3.7 Helena: A Plausible Intentional Learner

Like Audrey, Helena of School D, had limited prior knowledge despite being a Year 12 student. Her pretest score of 15%, same as Audrey's, was the lowest in the Human Biology class. However, her pretest-posttest gain of +37% ranked her the fourth in her class in terms of improvement.

Before instruction, Helena's conception was intelligible but not plausible based on her online tests results and her conception of the gene in the pretest open-ended questionnaire item (see Table 8.11). After instruction, status analysis of the interview transcript and online test results indicated that her conception was intelligible and plausible. Her conception was not fruitful as she did not think that the genetics which she had learnt could be of any use to her after the TEE.

Table 8.11

*Status Analysis of Helena's Gene Conception*

| Student (School/ Class) | Postinstructional Interview: Quotes (Interviewer's Question in bracket)/Episodes | Online Tests (Pretest or Posttest)/ Log file (LF: name of *BioLogica* activity / Date) | Conception Status Elements |
|---|---|---|---|
| Helena (D/HB) | | "It [A gene] has the characteristics that are inherited onto a child by the parents"(Pretest Q1) | Intelligibility (+LANGUAGE)<br>Plausibility (−METAPHYSICS) |
| | | Online tests (Pretest 15%) | Plausibility (−REAL MECHANISM) |
| | | Online tests (0% for items of Type V in both pretest and posttest | Plausibility (−METAPHYSICS) |
| | | Online tests (pre-post gain 37%)<br>"that genes are used to determine traits in individuals" (post Q1) | Plausibility (+EPISTEMOLOGY) |
| | "Um, like, with *BioLogica* we have to change the genes [and] the traits of them, that was really good, I liked doing that. And you can't really do that in textbooks, and you can do it on *BioLogica*. It was really good." | | Plausibility (+METAPHYSICS) |
| | "After the exam. Well, not for me it [genetics] won't [be useful] 'cause I'm not gonna be in that field but, I think it will be for other people. Yeah. Like for example Paul. He wants to be a doctor." | | Fruitfulness (−PROMISE) |

Helena was probably an intentional learner (Bereiter & Scardamalia, 1989) (see section 2.2.12) as she was always aware of her beliefs and intentions and sought help whenever she needed. For instance, in the *BioLogica* activity *Monohybrid,* she sought help twice for a practice session to check out the *tails rule* of the Dragons (Appendix 3, Document A3.7.1, lines 8-9 and 12-13) and once she asked helped for meiosis (lines 21-22). It was also during this activity that Helena had peer support from May (see section 7.4.4). She used both metaconceptual and metacognitive strategies in her learning and it appeared that her learning was intentionally initiated and was under her control (Sinatra & Pintrich, 2003a).

### 8.3.8 Phoebe: A Fruitful and Articulate Reasoner

Among all the students I interviewed in the three schools, Phoebe was perhaps the most articulate interviewee who showed a genuine interest in genetics and *BioLogica* (see Table 8.12).

Table 8.12

*Status Analysis of Phoebe's Gene Conception*

| Student (School/ Class) | Postinstructional Interview: Quotes (Interviewer's Question in bracket)/Episodes | Online Tests (Pretest or Posttest)/Log file (LF: name of *BioLogica* activity/Date) | Conception Status Elements |
|---|---|---|---|
| Phoebe (D/HB) | | "*they help determine your physiology ie: height, body shape, hair/eye colouring etc<br>*they determine what diseases you're prone to - if its genetic/hereditry (sic)<br>*you have 2 sets of genes - from both parents<br>*gene's (sic) can be altered in terms of genetically modified food with enhanced protein etc" (Pretest)<br><br>"that they alleles which dertimine (sic) traits. the ratio of inheritance differs on the sex chromosomes compared to the autosomal." (Posttest) | Intelligibility (+LANGUAGE; +EXEMPLAR) |
| | ("Can you relate what you learnt with Dragons to the human condition?")<br>"Yes. Yeah, I can" ("In what ways?")<br>"Oh, um, in sex linkage. So we have, they have colour and fire breathing, differences. I can relate that to say, haemophilia, and muscular dystrophy, in humans." | | Plausibility (+P ANALOGY) |
| | "Well, if say I was about to have a child or something, I'd know the precautions to take or, I'd know that there were options. So, no, it's really useful. I think everyone should be taught about all those options in genetics. Should be mandatory." | | Fruitfulness (+PROMISE) |

Phoebe's prior knowledge of genetics reasoning was the best in her class as indicated by in her pretest score of 69%. Her preinstructional conception was at least intelligible-plausible. In the postinstructional interview, she said that she had been absent for a whole term because of illness and she worked very hard to catch up with her progress. Log files analyses and classroom observations indicated that she completed all the seven activities assigned by Ms Elliott engaging in each one up to five times for which she had generated 18 log files (see Appendix 1, Table A1.7.3), the highest number for any of her classmates. Her postinstructional conception was clearly fruitful although her pre-post gain was only +16%. The ceiling effect (see Chapter 7) might have curtailed her gain.

### 8.3.9 John: A Plausible but Unintentional Learner

John had made no pretest-posttest gain and had the lowest score in the teacher's genetics test in the Biology class. Analysis of the status of John's conception may shed light on why he did not make progress in genetics reasoning as did other students in School D such as Audrey and Helena (see Table 8.13).

Status analysis in Table 8.13 shows that John's learning after instruction was intelligible and plausible but not fruitful. More importantly, it shows that his learning was not intentional according to Bereiter and Scardamalia (1989). As can be seen from the quotes in Table 8.13, John appeared to find learning easy and quick but he seldom made comments about his own learning; nor was he aware of what he did not know or understand—"a vital part of intentional learning" (Bereiter & Scardamalia, 1989, p. 375). John commented in the postinstructional interview about learning with the *BioLogica* Dragons:

> I think it's a good idea, you know you can…it makes the person, the individual thinks more for themselves, so they can kind of muck around with it saying, ah I think I want a pink Dragon, and see if I can do it, so they go ahead and do it and see what happens, so it helps with their learning…

Although he mentioned about "the individual thinks more for themselves," he did not appear to monitor and regulate his own learning in a metacognitive way. John was not likely an intentional learner.

Table 8.13

*Status Analysis of John's Gene Conception*

| Student (School/ Class) | Postinstructional Interview Quotes | Online Tests (Pretest or Posttest) | Conception Status Elements |
|---|---|---|---|
| John (D/B) | "Well I guess yeah, it [*BioLogica*] showed us the effects of mixing genes from different parents, and we learnt about the way dominant and recessive genes work, and the difference between autosomal and sex linked [inheritance], and stuff like that. " [a] | | Intelligibility (+LANGUAGE; +IMAGE) |
| | "And I don't think I would have, it wouldn't have sunk into my head as much as if we just sat in class talking about it, rather than actually doing it on the computers, because you can actually see from the results of like a baby Dragon, the effects." | | Plausibility (+LAB EXPERIENCE) |
| | "So the computers give you the answer straight up anyway, so you don't need the help or the aid of the class or the teacher." [b] | Online tests (Pretest 39%; Gain 0%) | Fruitfulness (–POWER) |
| | "I don't exactly agree with the TEE, I don't understand why life has to be decided on this one year and decided about a three hour exam and what you scored in that exam, because when you go out into the work force, you're not going to be put under situations where you're going to be writing an exam for three hours for your job, unless you're a journalist or something." | | Fruitfulness (–PROMISE) |
| | "Yes it is important to remember it...Little things that will twig in our heads, about what we have actually learnt. Which is usually the best way to learn." [c] | | |

[a] He appeared to learn with *BioLogica* as an activity but not a goal (Bereiter & Scardamalia, 1989).

[b] He might imply that learning with *BioLogica* was quick and easy learning.

[c] It appeared that he considered memorization as an important part of learning genetics.

### 8.3.10 Common Themes in Status of Students' Conceptions

In the preceding sections, I have analysed nine interviewees' gene conceptions using Thorley's (1990) status analysis categories and Hewson and Lemberger's (2002) methods. This has proved to be a powerful way of determining students' status of their conception.

In the nine student cases, the recurring theme—already mentioned in the results Chapters 4 and 7—is that active engagement in the *BioLogica* activities or other interactive multimedia (as in School C) was not enough for the development of genetics reasoning (see Table 8.14).

Table 8.14

*Comparison of Nine Interviewees' Genetics Reasoning, Conception Status and Usage of BioLogica*

| Student (School / Class [a]) | Pretest[b] (%) | Pretest-posttest Gain (%) | Status [c] Change (Thorley, 1990) | Number of *BioLogica* activities completed | Names of *BioLogica* activities (trials/number of log files) | Usage of *BioLogica* (estimated time in hours [d]) |
|---|---|---|---|---|---|---|
| Matthew (A) | 33 | +67 | IP→ IPF | 5 | *Introduction* (1), *Monohybrid* (1), *Meiosis* (0), *Horn Dilemma* (1), *Scales* (1) | High (2) |
| Eric (A) | 17 | +16 | I → IP | 3 | *Introduction* (0), *Monohybrid* (0), *Meiosis* (1) | High (2) |
| Terri (C/2) | 0 | +57 | I → IPF | 5 | *Introduction* (0), *Meiosis* (0); *Monohybrid* (2), *Mutations* (0), *Inheritance* (0) | Medium (1) |
| Andrea (C/1) | 29 | +58 | IP → IPF | 6 | *Introduction* (0), *Meiosis* (1), *HornDilemma* (0), *Monohybrid* (1), *Mutations* (1), *Mutation Inheritance* (1) | High (2) |
| Elaine (C/2) | 29 | +28 | I → IP | 4 | *Introduction* (0), *Meiosis* (0), *Mutation* (0), *Mutation inheritance* (0) | Medium (1) |
| Audrey (D/HB) | 15 | +47 | I → IPF | 7 [e] | 9 log files (at least one per activity) | High (4) |
| Helena (D/HB) | 15 | +31 | I→ IP | 7 | 9 log files (at least one per activity) | High (4) |
| Phoebe (D/HB) | 69 | +16 | IP → IPF | 7 | 18 log files (at least one per activity) | High (5) |
| John (D/B) | 39 | 0 | I → IP | 9 [f] | 10 log files (at least one per activity) | High (4) |

[a] 1 = Ms Claire's class ; 2 = Mrs Dawson's class ; B = Biology class ; HB = Human Biology class.

[b] The scores were based on the local pretests and posttests (parallel items).

[c] Status is represented by I for *intelligible*, IP for *intelligible-plausible* or IPF for *intelligible-plausible* and *fruitful*.

[d] Based on video data (School A), online self-reports (School C) and log files (School D)

[e] *Introduction, Rules, Inheritance, Meiosis, Monohybrid, Mutations* and *Sex Linkage*.

[f] *Rules, Inheritance, Meiosis, Monohybrid, Mutations, Sex Linkage* and *Scales.*

I have argued that the construct of *mindfulness* (Jonassen, 2000; Salomon & Globerson, 1987) is a plausible explanation for some students being unable to improve their genetics reasoning despite their high level of engagement with the *BioLogica* activities. If status is "the hallmark of all forms of conceptual learning" (Hewson & Lemberger, 2000, p. 123), the time and effort for students spent in using the *BioLogica* activities did contribute to learning in some students but not in others. Mindfulness—a construct used by Jonassen in arguing for his idea of computer microworlds as mindtools for engaging in critical thinking—is probably related in some ways to the intentionality of learners. I have discussed in Chapter 7 that Kath in the Human Biology class in School D did not appear to be learning mindfully with the MERs. Unfortunately, as Kath did not like to be interviewed, I did not have the opportunity to explore this issue further. Learning of students like John and Kath who made little improvement in genetics reasoning despite being actively engaged in the computer activities may be better explained in terms of the "metaknowledge for intentional learning" (Bereiter & Scardamalia, 1989, p. 376). This notion may be paraphrased and simplified as (1) learning as problem solving, (2) learning how to learn, and (3) learning what one does not know. What should science teachers do to support these students with lower prior knowledge who appear to work hard? I will discuss this in the conclusions in Chapter 9.

## 8.4 Discussion and Conclusions

In discussing the findings of this chapter, I attempted to synthesise the cross-case analyses in the preceding sections in response to the two research questions 8.1 and 8.2 (see section 8.1) that have guided the analyses. Some theoretical frameworks from Chapter 2 are also used in the discussion.

### 8.4.1 MERs Supported Three-dimensional Conceptual Learning

In response to the first research question, the cross-case analyses in the preceding sections suggest that *BioLogica* or its MERs did provide students with complementary information and processes of genetics, particularly about the genotype-phenotype relationship. Instead of using only the abstract terms about the new entities of genetics, *BioLogica* features visual-graphical representations, co-deployed simultaneously with textual descriptions and explanations.

The MERs appeared to have intrinsically motivated many students across the three case schools. Such motivations resulted from the interaction of the situational interests (salient features) of *BioLogica* and the students' individual interests. From the conceptual-learning perspective, the MERs increased the intelligibility of concepts of genetics so that students could continue to engage in their learning towards plausibility and fruitfulness as reviewed in Chapter 2, section 2.2. Mayer and Moreno's (2002) cognitive theory of multimedia learning (see section 2.3.5.1) can be useful in explaining how the simultaneous deployment of MERs—such as displaying the animation of meiosis processes in progress in one window and a question posed to the students in another window juxtaposed with buttons or Tools with which the students can use to manipulate these representations—might have helped the students in their conceptual learning. Accordingly to three embedded theories in Mayer and Moreno's theory, it is assumed that students process the visual and verbal material in different ways (dual coding theory of Paivio, 1986) which are mediated by prior knowledge (from long-term memory) for integration because the working memory capacity is limited (cognitive loading theory of Chandler & Sweller, 1991) (see Figure 2.12).

Across all three cases and the embedded subunits, a recurring theme is the role of visualisation being repeatedly mentioned by many students. Particularly, when engaged in *BioLogica* activities, those students in Schools A and D (see Tables 4.3 and 7.2) found them both intrinsically motivating and useful for understanding. For School C, the students did not use *BioLogica* as often so that the class-wide data could not provide strong evidence for this theme. For School D students, problem solving allowed them to find their conceptions plausible and for some fruitful.

Although we have seen earlier in thesis that interviewees in both Schools A and C used different formats of representing the genes, it was only in School C that students had the opportunity to make their representations of genetics explicit through class presentations. Every girl in the two classes took part in brief (about 10 minutes) group presentation based on the information of the website *Your Genes, Your Health*. As shown in Figure A2.6.1 in Appendix 2, the girls used different ways of representing the genetics of human disorders—Erika used mainly verbal-textual representation aided by gestures, Amelia used visual-graphical representation and Isabelle used both—which can be interpreted in terms of Dekeyer's (2001) theory of individual *representational preferences* (see section 2.3.9.3). Dekeyer's theory attempts to explain the mechanism between the incongruence between students' learning strategies and instructional strategies in connection with knowledge construction.

Furthermore, the analysis of conceptual status of nine interviewees in the preceding sections provided more evidence for explaining the finding that School C students did not outperform those in School A in terms of genetics reasoning (see Chapter 6). It appeared that the MERs in *BioLogica* better supported the development of reasoning by constraining interpretation of phenomena. Online multimedia such as the website *Your Genes, Your Health* provide complementary information, which may not support learning by constraining interpretation but they did likely support learning by fostering deeper understanding of gene structure and function. As discussed in Chapter 6, School C girls developed more sophisticated gene conceptions and greater ontological conceptual change than their cohorts in School A.

### 8.4.2 MERs raised Conception Status

As for the second research question 8.2, the analysis of the nine interviewees' conceptual status has provided new insights into how to judge a high status of a new conception.

Some students like Eric of School A whose postinstructional gene conception was judged to be only intelligible using Venville and Treagust's (1998) framework were found to have a higher status when Thorley's (1990) framework was used. If we compare the conceptual change of Audrey and Phoebe of School D, we can see that they had quite different prior knowledge (see Table 8.14), and Phoebe's posttest score was also much higher. Although online test results indicated that Audrey improved in her Type V reasoning (both items in the pretest were not correct; one of the two items was correct in the posttest), no interview questions probed her conception of the gene. Phoebe had all two Type V items correct in both the pretest and the posttest. Despite these differences, a status analysis using Thorley's framework revealed that both students were found to have an intelligible-plausible-fruitful conception after instruction. The analyses suggest that Thorley's framework allows the students' conceptual learning to be interpreted in a more multidimensional way. In particular, the status elements for fruitfulness, namely, POWER and PROMISE, are related to the social/affective dimension defined in Tyson et al.'s (1999) multidimensional CCM.

As can be seen in both cross-case analyses, the findings in School D appeared to be most significant across the three cases. School D students used most of the *BioLogica* activities regularly in their learning as an integral part of Ms Elliott's teaching. These students were highly motivated both intrinsically and extrinsically because they had to prepare for the TEE and so these students were able to benefit from the constraining function of MERs as their learning in Year 12 was geared towards problem solving. Furthermore, the complete set of log files allowed more thorough analysis not possible in Schools A and C. However, the pressure of the examinations and the tight time constraints did not allow these very interested students to enjoy learning with the new opportunities provided by MERs as much as those students in Schools A and D.

### 8.4.3 Final Comments

This chapter has focused on the students' conceptual learning in relation to the multiple external representations of genetics featured in the interactive program *BioLogica*.

The cross-case analyses, guided by the two research questions 8.1 and 8.2, have been conducted on the class-wide data across three case schools (Schools A, C and D) as well as the data from the 26 target interviewees across the five classrooms at these study sites. In-depth analyses of nine selected interviewees sought to determine their conceptual change using Thorley's framework and to explore the plausible explanations or a causal network to explain learning with MERs. In so doing, I have tried to move from a causal network at a case-level to a synthesis of a cross-case causal network (Miles & Huberman, 1994) to explain the similarities and differences of student learning with MERs across these three cases. This chapter has provided some common threads for drawing conclusions in the next and final chapter.

# Chapter 9

# Discussion and Conclusions

## 9.0 Overview

This chapter ties together all the chapters to discuss the findings and draw the overall conclusions of this study. The challenge is to make meaning from the massive amount of data collected, analysed and interpreted in order "to identify patterns and construct a framework for communicating the essence of what the data reveal" (Patton, 1990, p. 372). In doing so, I organised this chapter in three major parts.

The first part is about the discussion of within-case and cross-case analyses from the results chapters and Chapter 8 to argue for an overall conclusion of the study as a single case. In some places in the first part, I need to use further cross-case analyses to discuss and interpret the results. The second part of this chapter summarises the overall findings in terms of some general assertions in response to the research questions and draws conclusions of the study—the implications of the findings and suggested further and future research. The third part summarises the overall limitations of this study. In drawing conclusions for the whole study by synthesising the assertions in each of the results chapters, I am using some of Miles and Huberman's (1994) tactics in testing or confirming the local findings (see section 3.8). Whereas the major findings are about students' conceptual learning of genetics reasoning with multiple external representations (MERs) in relation to conceptual change analysis and the functions of MERs, the findings from the second case study in School B (Chapter 5) have provided some new insights into the role of teacher knowledge in using ICT in science education. Wherever necessary, links and cross-references are given in the running texts or in figures and tables to assist readers in making connections to other relevant parts of the thesis. The Finale ends this last chapter, as if in a symphony, when the theme of this thesis reappears.

## 9.1 Teaching and Learning with MERs of Genetics: An Overall Discussion

The first part discusses the general scenarios of teaching and learning with *BioLogica* or its MERs of genetics across the four case schools. Strictly speaking, I refer to the students in the case studies in Schools A, C and D although some of the discussion may also refer to School B where Miss Bell taught briefly.

In the following sections, I will discuss the 11 themes identified in the various results chapters to develop a possible causal network in a graphical display which is then explained in a causal network narrative (Miles & Huberman, 1994).

### 9.1.1 Teachers' Expectations and Beliefs

As reported in the results chapters (see sections 4.2, 6.2 and 7.2) and in the cross-case analyses chapter (see section 8.2.1), the common theme in the teachers' expectations was motivational to suit their teaching.

In School A, Mr Anderson was concerned about completing the curriculum requirements and believed that *BioLogica* would motivate the students to speed up their learning and develop better understanding of genetics. However, he did not believe that students might learn better when they enjoyed their learning. For Ms Claire and Mrs Dawson of School C, they emphasised the diverse learning styles of the girls and that *BioLogica* activities would provide yet another way of learning genetics. Their teaching focused on the forefronts of human and molecular genetics and not as much on solving problems of Mendelian genetics as in School A. In School D, Ms Elliott was under pressure to prepare her students for the Tertiary Entrance Examinations (TEE) and expected *BioLogica* would motivate her Human Biology class. Ms Elliott spent more time in trying out the software than the other three teachers and had a stronger belief in the pedagogical use of ICT for engendering understanding. The teachers' expectations and beliefs, as will be discussed in the next section, appeared to be an important determinant of their students' learning process and outcomes. However, the motivational goal did not suffice in bringing about fruitful conceptual learning.

### 9.1.2 Teachers' Actions in Integrating, Implementing and Using *BioLogica*

Multiple sources of data suggested that teachers' expectations and beliefs affected the way in which they made their decisions to use selected *BioLogica* activities, and how many to use, in their teaching of genetics. Subsequently, these decisions determined the students' learning opportunities with the MERs. Technical issues, too, affected the usage of the software in School A (see section 4.3.3.2) and to a small extent in School C (see section 6.3) but not in School D. The number of *BioLogica* activities and the estimated usage time of students in Schools A, C and D (see Table 8.14) indicated that the Year 12 students in School D used the highest number of *BioLogica* activities, most regularly, than students in Schools A and C. Indeed, Ms Elliott used *BioLogica* as an integral part of her teaching. In contrast, School C students did not use *BioLogica* as often as expected.

The finding about lower usage of *BioLogica* in School C initially appeared surprising as the girls in School C each owned a laptop computer. Besides the online self-reports (see Table 6.2), my persistent observations in the two classrooms, the interviewees' comments, and the teachers' opinions all pointed to support the claim that the girls did not use *BioLogica* as often as the students in School D and probably took less time than those in School A. However, Ms Claire and Mrs Dawson had students use the interactive multimedia from websites about human and molecular genetics that also featured MERs. Nevertheless, these activities provided complementary information and processes rather than constraining students' interpretation of the phenomena in question, that is, Mendelian genetics (see section 6.5). These MERs also function to encourage students to construct deeper understanding. As such, the contribution of *BioLogica* to learning in School C is not significant except for some interviewees such as Andrea who claimed to have used six activities and found them useful for learning (see section 6.3.3.3). Overall, the contribution of *BioLogica* to student learning appeared to be important with strong evidence grounded in rich data from multiple sources as in School D (see Chapter 7).

### 9.1.3 Individual Interests, Situational Interests and Motivations

Across all three schools, students' personal interests in genetics were generally high except for a few students such as Eleanor of School A (see section 4.4.1.1) and

Nancy in School C (see section 6.4.3.3) who did not like genetics and to whom the salient features of *BioLogica* activities did not appear to be motivating.

The salient features of *BioLogica*, particularly visualisation and instant feedback to students' keyboard actions, are considered as situational interests (see section 2.2.8.2). Both personal interests and situational interests contributed to intrinsic motivations (see section 2.2.8.3). Cross-case analyses in Chapter 8 (see section 8.2.1 and Table 8.1) have revealed that more students in School A and in the Human Biology Class in School D were intrinsically motivated than those in School C. *Peer support*—one of the intrinsic motivational features first identified in School A—turned out to be one important factor conducive to the learning of students with lower prior knowledge such as Audrey and Helena (see the vignette of Helena and May in section 7.4.4) in the Year 12 Human Biology class in School D. School D students also were intrinsically motivated in their learning because they believed that the *BioLogica* activities were useful for learning to prepare for the TEE (see section 7.3.3).

### 9.1.4 Student Engagement in *BioLogica* Activities

The preceding sections have discussed how several factors determined students' learning opportunities using *BioLogica*. Multiple sources of data—observations, documents, log files, interview and lesson transcripts, and online self-reports—provided opportunities for analyses and interpretations to evaluate student engagement in the *BioLogica* activities.

Most students in Schools A, C and D were found to be highly engaged when they worked on a particular activity. However, those students who did not like genetics or those School C girls who disliked the *BioLogica* Dragons seldom used the activities and in some cases used none at all. In the results chapters and in the cross-case analyses chapter, we have seen that the time which students spent in completing the *BioLogica* activities did not always parallel their performance in the online tests. Nelly in the first case study was an example: She appeared to work very hard through the *BioLogica* activities (see section 4.6) but her score regressed in the posttest. John in the Biology class in School D was another similar example who did not make improvement despite active engagement in *BioLogica* activities. In the next section, I will articulate the construct of mindfulness to provide a plausible explanation for this cross-case discrepancy.

### 9.1.5 Role of Mindfulness in Learning

Although *mindfulness* (Salomon & Globerson, 1987) was first proposed to describe generic learning, Jonassen (2000) discussed the role of mindfulness within the contexts of learning with the computer as a mindtool. The meaning of mindfulness in a special context of this study has already been discussed in the literature review chapter (see section 2.3.12).

As the online tests used in the fourth case study had the largest number of two-tier items, the online tests should more accurately measure whether students could perform their genetics reasoning. The mismatch of effort and performance again emerged as a recurring theme. Analysis of the pretest-posttest scores indicated that students like John, Kath or Margaret in School D did not progress, or even regressed, in their posttest scores. The analyses of the log files corroborated the assertion that mindfulness might be important to learning when students interacted with the MERs (see Table 7.5). Engaging in more *BioLogica* activities or doing so more regularly did not necessarily translate into improved performance in the online tests on genetics reasoning. As discussed in the results chapters, learning through interaction with the MERs needs to be mindful in order that learning can be meaningful in a Ausubelian (1968) sense (see sections 4.4.2.1 and 7.4.2).

### 9.1.6 Role of Prior Knowledge

Students' prior knowledge consistently constituted a major predictor for their learning outcomes in terms of genetics reasoning. As reported in the results chapters, the students in Schools A, C and D, who scored higher in the online pretests, were likely to do the same in their posttests (see the cross-case analysis display in Figure 8.1). These findings lend more support to what has been found in past studies in other domains as summarised by Duit and Treagust (1998) in their review of the literature that:

[d]omain-specific preinstructional knowledge has proven to be the key factor in determining learning and problem solving in research in all science domains. Ausubel's (1998, p. vi) famous dictum, 'The most important single factor influencing learning is what the learner already knows…' has been corroborated many times since it was written. (p. 19)

As would be expected, Year 12 students (aged 16 to 18), who had already learnt genetics in Year 10, were generally more knowledgeable about genetics than the Year 10 students (aged 14 or 15) who had never learnt genetics before. Within the same Year/age group in School D, however, students with less prior knowledge as indicated by the pretest scores made more progress in terms of their pretest-posttest gains in genetics reasoning than did their classmates with higher prior knowledge (see Table 7.9). As I have already argued in Chapters 7 and 8, a possible ceiling effect might have prevented the high-achieving students from making similar gains.

To explore the role of students' prior knowledge in their learning based on their online test scores, I calculated the mean score of all 65 participating students in each of Schools A, C and D who did both the pretest and the posttest. The pretest-posttest comparison of the mean scores of the students across the three schools is displayed in Figure 9.1.

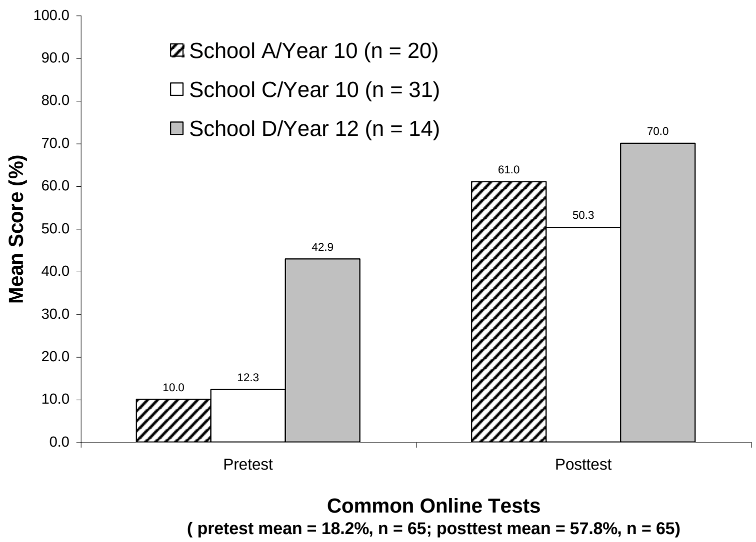



*Figure 9.1* Pretest-posttest comparison of mean scores across Schools A, C and D based on five common two-tier items of genetics reasoning Types I, III, IV and VI (also see Figure 8.1).

As can be seen from Figure 9.1, the Year 10 students of Schools A and C had much less preinstructional knowledge of genetics reasoning compared to the Year 12 students of School D. Yet, the Year 12 students had only a slightly higher posttest mean score than those of the Year 10 students.

In the literature review in section 2.3.9.1, I pointed out that a learner's prior knowledge is important in learning with multimedia according to the cognitive theory of multimedia learning (Mayer & Moreno, 2002). Accordingly, a cognitively active learner perceives the words and pictures and holds them in the verbal and visual working memories before the learner mentally builds connections between the two. The learner's prior knowledge integrates the visual and verbal mental models in constructing deeper understanding of the domain when the learner iteratively builds referential connections between the visual and verbal mental models (see Figure 2.11).

As I have repeatedly used the evidence from the pretest-posttest comparisons to make claims and assertions, I must reiterate that the online tests for School D were reliable based on the fact that the results were consistent with other data when triangulated. For instance, the high-achievers—such as Karl (pretest:100%; posttest 100%), Bob (pretest: 77%; posttest: 85%) or Phoebe (pretest: 69%; posttest: 85%)—displayed better genetics reasoning than those with low prior knowledge on the basis of both the teacher's test scores and the log file analysis of their tasks during the *BioLogica* activities. Furthermore, this is because the version of the online tests for School D had the greatest number of parallel two-tier items—two items for Types I to V genetics reasoning and three for Type VI so that the likelihood of getting a right answer by guessing is very low. In addition, in order to check the effectiveness of the items, Ms Claire of School C tried out the pretest version for School C and scored 100% (see Table 9.1 for results of full-scorers).

Table 9.1

*Participants who Scored 100% on Common Online Test Items*

| Online Test (5 parallel two-tier items) | Student who Scored 100% (School/Year /Class) | Teachers who Scored 100% (School) | Remarks |
|---|---|---|---|
| Pretest<br>(Mean = 18.2%; $n$ = 65) | Karl (D/Y12) | Ms Claire (C) | Only Ms Claire (C) and Miss Bell (B) tried out the pretest |
| Posttest<br>(Mean = 57.8%; $n$ = 65) | Doug (A/Y10)<br>Matthew (A/Y10)<br>Karl (D/Y12/Biology)<br>Bob (Y/Y12/Biology) | Nil | Only Miss Bell (B) tried out the posttest |

### 9.1.7 Functions of MERs: From Theory to Practice

The functional taxonomy of Ainsworth (1999) was rarely cited in the literature except among those researchers on multiple representations. Yet Jonassen (2001) commente that the issues of multiple representations are "critical to the entire field of learning" (p. 327) (see Chapter 1). This four-case study has provided some new findings about how teaching and learning of genetics involving *BioLogica*—that features linked multiple external representations (MERs)—can be interpreted in terms of Ainsworth's three functions of MERs (see Table 9.2).

To explore the functions of MERs, the log files that tracked the students' interaction with *BioLogica* were analysed. However, only in School D could I collect a complete set of all the students' log files. In School D, Ms Elliott fully integrated the software in her teaching and students used most of the activities (seven in Human Biology class and nine in Biology Class) regularly for the second half of most lessons. The log files provided information about student-MER interactions with respect to the questions of *when*, *in which activities*, *for how long* and *what communications and interactions occurred* with student usage of *BioLogica* activities. When data available from other sources could be mapped to those students whose log files were analysed, I attempted to examine how such interactions could have contributed to student learning in terms of genetics reasoning (see vignettes in sections 7.4.4 and 7.4.5). As such, the results from School D are the most useful in exploring the MER functions in this study.

Table 9.2

*Cross-case Comparisons of BioLogica Usage and Learning Outcomes*

| Case School/Year /Class (*n* = number of students) [a] | Usage of *BioLogica* (number of activities; estimated time [b]) | Two Reasoning Types [c] with Highest Gains in Mean Scores | Log Files Availability | Motivation in Using *BioLogica* | Quality of Data |
|---|---|---|---|---|---|
| A/10 (*n* = 20) | Medium (3; 2 hours) | Types I (+83%) and III (+ 73%) | Interviewees and class-wide: incomplete | High | Strong |
| C/10 /Class1 (*n* = 14) | Low /Medium (2-5; 0-1.5 hours) | Types I (58%) and III (+68%) | Interviewees: incomplete; class-wide: none | Medium | Weak |
| C/10/Class 2 (*n* = 17) | Low /Medium (2-5; 0-1.5 hours) | Types II (+80%) and III (65%) | | Medium | Weak |
| D/12 /Human Biology (*n* = 8) | High (7; 4 hours or more) | Types IV (+31%) and VI (+33%) | Complete | High | Strong |
| D/12 /Biology (*n* = 6) | High (9; 3 hours or more) | Types III (+18%) and IV (+9%) | | High | Strong |

[a] Only data of students who completed both the pretest and the posttest were included.

[b] Estimation of time was based on video data (Schools A), online self-reports (School C) and log files (School D).

[c] Genetics reasoning was based on online tests (parallel items; both local and common items).

In School A, although Mr Anderson used *BioLogica* as a supplement to his teaching and that his students had limited access to the computer room, most of the students were intrinsically motivated when they worked through the three *BioLogica* activities. Mr Anderson did make the best use of three 80-minute computer sessions to provide new opportunities for students' learning with *BioLogica*. Furthermore, Mr Anderson linked his teaching several times to students' previous experiences in using the *BioLogica* activities (see section 4.3.2). Despite not all the log files being collected from School A, the results were useful in discussing the student learning in relation to the functions of the MERs of *BioLogica*.

In considering the contribution of the MERs of *BioLogica* to students' development of genetics reasoning, the weakest evidence seems to come from School C because students only used two activities—*Meiosis* and *Monohybrid*—in class and not every student participated as their self-reports revealed.

I revisited the results chapters (Chapter 4, 6 and 7) and the cross-case analyses chapter (Chapter 8) to look for students' learning in relation to the functions of the MERs in *BioLogica*—to complement (information or processes), to constrain (interpretation/misinterpretation) or to construct (deeper understanding). I identified a set of abstractions across the cases summarised in Table 9.2 that involved the confirming evidence from multiple sources of data to different extents. I have used some of Miles and Huberman's (1994) tactics of generating meaning (see section 3.7.2) from the analyses and interpretations in the various results chapters and the cross-case analyses chapter. The table uncovered a new emerging theme that the Year 12 Human Biology class made substantial pretest-posttest improvement in two difficult types of reasoning in terms of percentage gain in scores, namely, effect-to-cause reasoning across generations (Type IV) (see Table 3.1) and process reasoning across generations (Type VI). Both types of reasoning were found to be most difficult for students in all the case schools. I consider this theme to infer that the use of *BioLogica* in School D was successful in supporting the learning of a group of students with lower prior knowledge, that is, those with low domain-specific preinstructional knowledge. I will articulate this meaning as one of the significant findings in the second major part of this chapter.

### 9.1.8 Visualisation, Instant Feedback and MERs

In Chapter 2, section 2.3.6, I reviewed some recent research studies on visualisation and conceptual learning, particularly the notion that *visualisation* can help students make connections between microscopic processes (meiosis and fertilisation) and Mendelian genetics. Visualisation and *instant feedback* are two recurring themes in this study. As discussed in the results chapters, most of the interviewee students in Schools A and School D and some in School C considered that these two important features of *BioLogica*, or the MERs, motivated learning and engendered understanding. I have revisited the respective results chapters and the percentages of interviewees who commented on these features are displayed in Table 9.3.

Table 9.3

*Cross-case Comparisons of Interviewees' Perceptions of Two Salient Features of BioLogica*

| School/Year Level (number of Students) | Visualisation/Number of Students (%) | Instant Feedback/Number of Students (%) |
|---|---|---|
| A/Year 10 (*n* = 7) | 6 (86%) | 4 (57%) |
| C/Year 10 (*n* = 16) | 6 (38%) | 2 (13%) |
| D/Year 12 (*n* = 13) | 12 (92%)* | 13 (100%)* |

*The interviewees in School D were prompted with these two features in the interviews.

There were actually three salient features identified by students in School A. The third feature, which I do not discuss further here, is *flexibility*—a rather loose construct—which was not easy to map to students' perception data and there were less students who considered the construct of flexibility useful for learning compared to visualisation and instant feedback. In terms of the functions of MERs, visualisation has to do with providing complementary information or processes whereas instant feedback by way of graphics and texts is more related to constraining interpretations (or misinterpretations) of phenomena. However, visualisation and instant feedback overlap each other to some extent. The high percentage of students in School D who considered these two features of *BioLogica* as important for their learning was commensurate with the local context. First, as discussed in Chapter 7, School D students, who were intrinsically and extrinsically motivated, used most of the activities of *BioLogica* and did so on a regular basis. As such, they came to appreciate visualising the different representations of genetics and getting instant feedback during reasoning and problem solving when they worked through the activities. Second, in preparing for the TEE, School D students found reasoning and problem solving an important part of their learning and visualisation effects and instant feedback constrained their interpretation or misinterpretation in the tasks. Studies from several areas of research disciplines have provided supporting evidence that visualising tools can help students make connections between visual and conceptual aspects of representations and thus serve as a vehicle for constructing their understanding (Wu et al., 2001)(see section 2.3.5).

### 9.1.9 Conceptual Change: Status and the Three Dimensions

In uncovering some common threads among the preceding cross-case analyses about student conceptual change in relation to other factors, I have generated a matrix (see Table 9.4) to compare and contrast the overall conceptual learning of the students in terms of the multidimensional CCM of Tyson et al. (1997) for global discussion of conceptual change using the class as a unit of analysis.

In this discussion, I intend to use the three dimensions—motivational, epistemological and ontological—of Tyson et al.'s (1997) multidimensional model for interpreting students' learning of genetics when they were engaged in the *BioLogica* activities. Case Study Two in School B is also included for a global comparison. As already discussed in different parts in the thesis, the usage of the *BioLogica* activities in School C was unexpectedly low despite School C being a laptop school. Nevertheless, the contribution the MERs from other online resources to students' conceptual learning of genetics should not be ignored. For the present discussion across all the four case studies, I only consider the contributions of the *BioLogica* activities to student learning.

As already generated as assertions in various results chapters, based on the data displayed in Table 9.4, the intention of each teacher using *BioLogica* was slightly different. Drawing from all the analyses and interpretations in the various results chapters and the cross-case analyses chapter, I found that the students' learning outcomes generally matched the teachers' intentions and expectations and the contextual factors in each classroom. The Year 10 students in School C did not outperform the Year 10 students in School A in genetics reasoning but their ontological progression in their gene conceptions was generally more sophisticated (Venville & Treagust, 1998). When the gene conceptions of the interviewees across Schools A, C and D were re-interpreted with Thorley's (1990) status analysis categories, I have constructed overall conceptual learning outcomes in terms of conceptual status as shown in column eight Table 9.4. It is interesting to note that Thorley's framework appeared more robust in determining the status of students' gene conceptions than Venville and Treagust's.

*Table 9.4*

*Cross-case Comparisons of BioLogica Usage and Three-dimensional Conceptual Change*

| Case School /Year /Class | Number of Students | | Usage of *BioLogica* (number of activities [a]; estimated time[b] ) | Motivation in Using *BioLogica* | Two Reasoning Types [c] with Highest Gains | Most Sophisticated Gene Conception [d] of Interviewees | Overall Conceptual Learning [e] of Interviewees | Quality of Data |
|---|---|---|---|---|---|---|---|---|
| | Girls | Boys | | | | | | |
| A/10 | 11 | 13 | Medium (3; 2.5 hr) | High | Types I (+83%) and III (+ 73%) | Gene as active particle | I → IP | Strong |
| B/10 | 17 | 11 | Low (1 hr) | High | ? | ? | ? | Weak [f] |
| C/10 /Class1 | 25 | 0 | Low /Medium (2-5; 0-2 hr) | Medium [g] | Types I (58%) and III (+68%) | Gene as productive sequence of instruction | I → IP/IPF | Weak |
| C/10/ Class 2 | 23 | 0 | Low /Medium (2-5; 0-2 hr) | Medium [g] | Types II (+80%) and III (65%) | ? | I → IP | Weak |
| D/12/ Human Biology | 3 | 3 | High (7; 5 hr or more) | High | Types IV (+31%) and VI (+33%) | Gene as productive sequence of instruction | I → IP/ IPF | Strong |
| D/12/ Biology | 10 | 1 | High (9; 4 hr or more) | High | Types III (+18%) and IV (+9%) | Gene as productive sequence of instruction | IP → IPF | Strong |

[a] See Table 9.6 for the set of *BioLogica* activities used in class for each school.

[b] Estimation of time was based on video data (Schools A and B), online self-reports (School C) and log files (School D); students in Schools C and D had access to *BioLogica* after the lessons.

[c] Based on the local online tests but the items on Types I, III, IV and VI were common across all Schools A, C and D.

[d] Based on Venville and Treagust's (1998) framework.

[e] Overall evaluation of conceptual change with Thorley's (1990) status analysis categories; I for *intelligible*; IP for *intelligible-plausible* and IPF for *intelligible-plausible-fruitful*.

[f] Only three students did the posttest at home and none of the students were interviewed.

[g] School C students regularly used online websites on human and molecular genetics (see Chapter 6).

### 9.1.10 Classroom Interactions and Learning

In all the classrooms in Schools A, C and D, only those students in the Human Biology class in School D made substantial preinstructional-postinstructional improvement in their genetics reasoning. Interview data also indicated that some of these students had developed a high status for their conceptions in terms of the status elements, POWER and PROMISE (Thorley, 1990) (see Table 2.3). Besides the highest number of *BioLogica* activities used in the most frequent fashion in School D compared with Schools A and C, two factors about classroom interactions appeared to be conducive to the learning of students with lower prior knowledge—*peer support* and *teacher scaffolding* within students' *zone of proximal development*.

#### *9.1.10.1 Peer Support*

*Peer support* was one recurring theme in intrinsic motivations which was identified in School A (see section 4.4.1.3) Among other data sources, the percentages of students who mentioned this theme in Schools A, C and D were respectively 25%, 5% and 38% (see Table 8.1). In School D, case studies of student dyads, Helena and May (see section 7.4.4), and Kath and Alina (see section 7.4.5), provided rich and thick descriptions in terms of vignettes to illustrate how peers learnt, or did not learn, from each other when they worked together in the *BioLogica* learning environment.

I attempted to use Miles and Huberman's (1994) "Making If-Then Tests" (p. 271) (see section 3.7.4) to validate the claim that peer support helped learning of students with low prior knowledge by selecting some instances from the within-case and cross-case analyses in the preceding chapters. Table 9.5 shows an abstraction of many sections and displays of data about peer support. As can be seen from Table 9.5, the instances used in the if-then tests were generally supportive of the claim that peer support can be critical for those with low prior knowledge even when working with a highly interactive computer program like *BioLogica*.

Table 9.5

*Making If-Then Tests to Validate Peer Support as a Claim*

| School/Year/ Classroom | If | Then | Cross-references, Comments and Quotes |
|---|---|---|---|
| School A/Year 10 | Peers worked together | They enjoyed more learning with *BioLogica* and helped each other in understanding. | Nelson and Mark of School A enjoyed learning together and claimed to understand more (see Table 4.4) |
| School C/Year 10 | The teacher encouraged the girls to discuss while working on *BioLogica* (Only Ms Clair did this.) | Peer support was not obvious in both classes; the interviewee girls with lower prior knowledge in Ms Claire's class appeared to make more pretest-posttest gains than their counterparts in Mrs Dawson's class (see section 6.4.2.3). | "Girls, it might be a good idea to do it together on one computer, and share, and then you can talk to each other about what's happening…" (Ms Claire/lesson/24May 2002) |
| School D/Year 12/Biology | One student with lower prior knowledge had worked with another with higher knowledge. | The student with lower prior knowledge could probably have made more progress | John (39% in both online tests) and Karl (100% in both tests) never worked together when using *BioLogica* |
| School D/Year 12/Human Biology | Peers worked together when using *Monohybrid.* | They learnt and understood more. | May, the peer tutor, supported Helena, the peer tutee, and Helena substantially improved her work (see section 7.4.4). |

#### *9.1.10.2 Scaffolded Learning within the Zone of Proximal Development*

*Teachers' scaffolding* is the second theme which became a significant form of classroom interaction in School D when Ms Elliott used *BioLogica* in motivating a group of uninterested students with low prior knowledge to learn Mendelian genetics for understanding and for preparing for the TEE (see Chapter 7).

Although each of the five teachers mentioned the potential of *BioLogica* in supporting the learning of students with low prior knowledge, only Ms Elliott adopted some strategies in integrating and implementing the computer-based learning towards this goal. Ms Elliott's success—in helping her students to make substantial improvements and empowering them to become more confident reasoners—epitomised how an interactive multimedia program could be used to support student learning.

First, drawing on the rich data from multiple sources, I have construed Ms Elliott's referent for her actions in teaching as one of social constructivism (Duit & Treagust, 1998) similar to Vygotsky's (1978) notion of the zone of proximal development (ZPD). Ms Elliott mentioned similar ideas in our conversations but did not directly refer to Vygotsky (see section 7.2). As such, Ms Elliott integrated and implemented *BioLogica* in her teaching in the two classes using the ZPD as an implied referent as illustrated by her scaffolding of Kath (see the vignette in section 7.4.6). Second, I argue that her actions were based on an intimate knowledge of her students' learning capabilities—part of Shulman's (1986) PCK (see next section). Whereas I suspect that other teachers did have this knowledge, they did not overtly base their actions on such knowledge, nor did they have the opportunity to do so because of the time constraints, technical issues or their own beliefs about teaching and learning.

### 9.1.11 Role of Teacher's PCK and Use of MERs

The role of teacher knowledge emerged from the second case study in School B as a useful construct for interpreting teaching in this study. Let me summarise how the teachers used *BioLogica* in their teaching across the four case schools, including School B where Miss Bell had her practice teaching as reported in Chapter 5. The preceding sections have suggested that the teachers made decisions to teach selected *BioLogica* activities, and how many, based on their beliefs and contextual factors in their school. However, based on observational data, self-reports and log files analyses, the students might have completed a slightly different set of *BioLogica* activities. This section discusses teacher knowledge in teaching genetics with *BioLogica*.

I argued in Chapter 5 that teachers using ICT in general, and *BioLogica* in particular, need a special type of Shulman's (1986) pedagogical content knowledge (PCK) similar to Friedrichsne et al.'s (2001) notion (see section 5.1). I also showed that Miss Bell had expanded this special PCK through her own reflections and that her personal beliefs and perceptions indirectly affected her PCK (see Figure 5.5). As the impact of teachers' beliefs and referents was part of the initial research question 2 and one of the specific research questions in all the four case studies, PCK is closely associated with how teachers can make use of the MERs in their teaching. PCK of a teacher is about his or her "ways of representing and formulating the subject that make it comprehensible to others." and "an understanding of what makes the learning of specific topics easy or difficult" (Shulman, 1986, p. 9). Indeed, as will be discussed in the next section, teachers' PCK is related to part of their causal network of knowledge.

Based on the analyses and interpretations of data from multiple sources, I compared and contrasted teachers' use of *BioLogica* in their teaching with other contextual information (see Table 9.6). Besides using *BioLogica*, teachers also had a repertoire of representing genetics (see Table 9.6 last column) which contributed to student learning in one way or another.

Data from multiple sources suggested that, except Miss Bell (see Chapter 5), each of the other four teachers had very good content knowledge about genetics and general pedagogical knowledge but varied knowledge about ICT in general, and *BioLogica* in particular. Ms Claire, Mrs Dawson and Ms Elliott might have more knowledge about using ICT in teaching than had Mr Anderson because of better computing facilities in their schools. Whereas Miss Bell and Ms Elliott had very good knowledge about *BioLogica*, Ms Claire and Mr Anderson also were cognisant of the *BioLogica* activities which they used in teaching. Mrs Elliott's familiarity with the *BioLogica* activities enabled her to carefully select, sequence and pace the *BioLogica* activities to support the learning of the students in her two classes of differing interests and prior knowledge, particularly those with lower prior knowledge (see Chapter 7).

To summarise this section related to a finding which has implications for science teacher education, I propose a model called *PCK-TT* —pedagogical content knowledge (PCK) for teaching with technology—that encapsulates theoretical frameworks from three different research disciplines (see Figure 9.2).

The model describes a special type of PCK needed by teachers in teaching science with interactive multimedia that feature MERs to engender understanding and conceptual change.

Table 9.6

*Case-ordered Matrix for Comparing and Contrasting Teachers' Use of BioLogica and Other Resources in Teaching*

| School/Year / Class | Teacher | No of Students | No of Lessons Observed | *BioLogica* Activities Used in Teaching [a] | Level of Integration [b] | Feedback on *BioLogica* (online tests/log files) | Level of Scaffolding | Use of Other Resources |
|---|---|---|---|---|---|---|---|---|
| A/Year 10 | Mr Anderson | 24 | 28 [c] | Three activities: (1), (3) and (4) | Medium (as a supplement) | No | Medium | OHP[d], Video, making cardboard model of DNA |
| B/Year 10 | Ms Bell | 28 | 6 | Two activities: (1) and (3) | None (one activity) | No | High | OHP |
| C/Year 10 /Class 1 | Ms Claire | 25 | 21 | Two activities: (3) and (4) done in class; Two others: (6) and (7) to be done after class [e] | Low (one new learning style) | No | Medium | OHP, data projector, online multimedia on human/molecular genetics, games, simulation, DNA extraction experiment |
| C/Year 10 /Class2 | Mrs Dawson | 23 | 18 | | | No | Low | |
| D/Year 12 /Biology | | 6 | 14 | Nine activities: (3) (4) (2), (5), (6), (7), (8), (9) and (11) | High (for understanding and examinations) | Yes (online tests) | High | Video, OHP |
| D/Year 12 /Human Biology | Ms Elliott | 11 | 15 | Seven activities: (1), (2), (3), (4), (5), (6) and (9) | | Yes (online tests and log files) | High | OHP |

[a] *BioLogica* activities the teachers organized for students to do in the computer room (Schools A, B and D) and classroom (School C): (1) *Introduction*, (2) Rules, (3) *Meiosis* (4) *Monohybrid* (5) *Inheritance*, (6) *Mutations*, (7) *Mutation Inheritance*, (8) *Dihybrid* and (9) *Sex Linkage* (10)*Horn Dilemma* and (11) *Scales.*

[b] Integration is used in a special context of this study—an arbitrary continuum from none (School B) to full (School D).

[c] Fourteen double lessons.

[d] Overhead Projection. [e] The students in School C each have a laptop computer with which they could use *BioLogica* after the lessons.

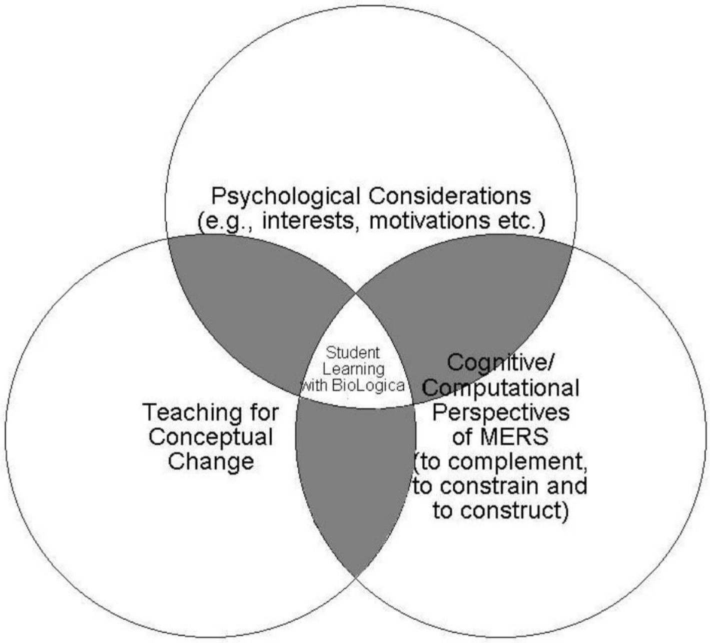



*Figure 9.2* Proposed *PCK-TT model* as denoted by the shaded area together with the centre or the intersection of the three sets in the Venn diagram.

### 9.1.12 A Synoptic Cross-case Causal Network

In the preceding sections, I have discussed the overall findings of the thesis with respect to student learning genetics with the MERs in *BioLogica*. Based on Miles and Huberman's (1994) method, I use, in this section, a synoptic cross-case causal network to graphically display the interwoven relationships of the events, participants and theoretical constructs for this study involving four schools, five teachers and six classrooms (see Figure 9.3).

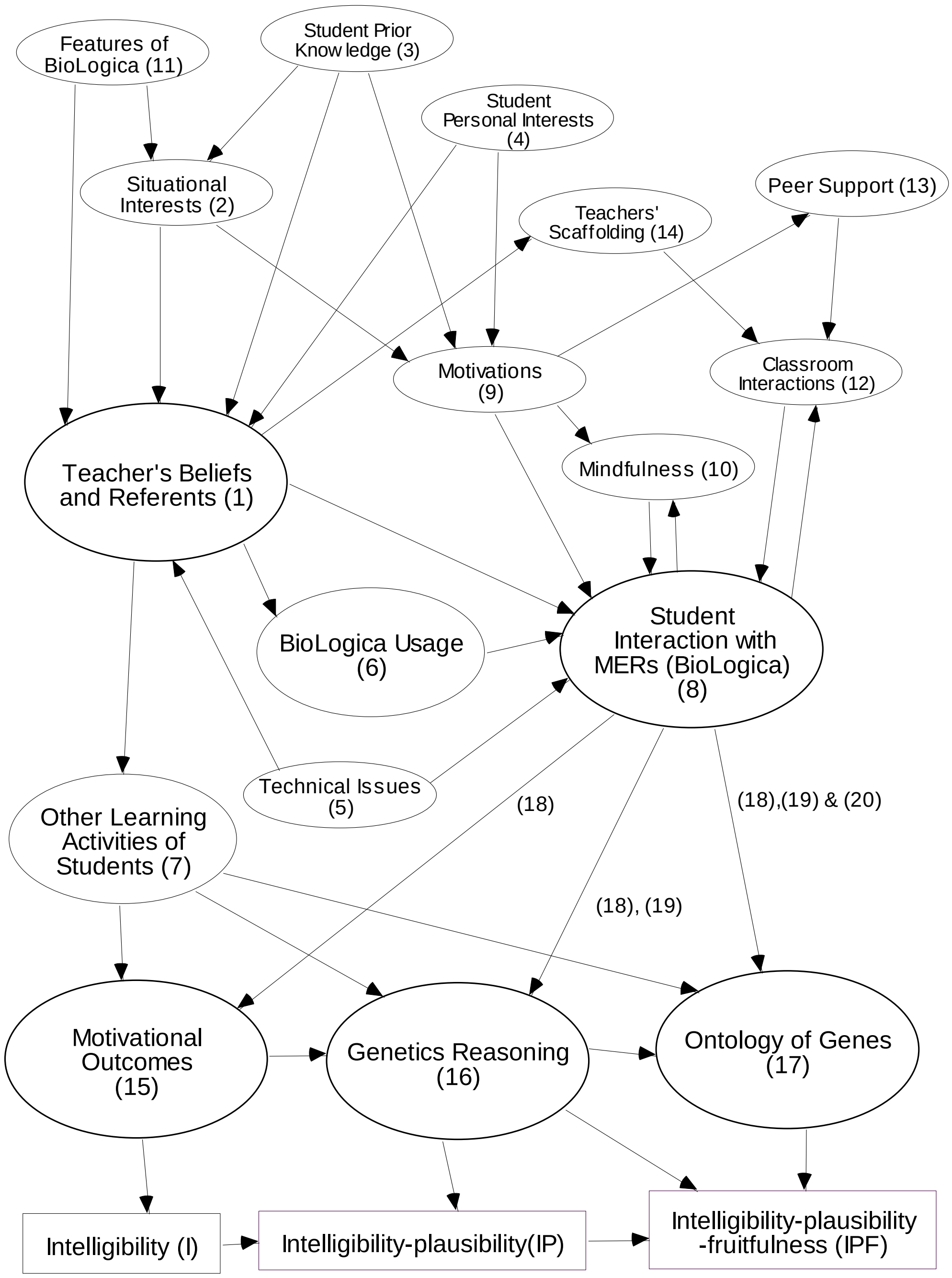
The arrows may not necessarily represent a causal relationship, nor do they indicate the strength of any kind of relationships they represent. The causal network model is described in a detailed *causal network narrative* in the following section as suggested by Miles and Huberman (1994). In this causal network narrative, I use a number in parenthesis to label the event, action or construct in each point. The number refers to a particular oval, block or arrow in Figure 9.3.

The four-case study of the teaching and learning of genetics with *BioLogica* that features rich multiple external representations (MERs) began when the teachers —including Miss Bell in School B—decided to participate in the research based on their beliefs (1)[30] that *BioLogica* may help their students in learning genetics. Their beliefs—in making the decision as to which activities or how many activities to use (6)—were underpinned by situational interests (2) related to the salient features of *BioLogica* (11), their knowledge about the preconceptions of genetics (3) and personal interests (4) of their students. However, the teachers' plans to use the *BioLogica* activities depended on technical issues (5) including the computing facilities in their schools such as the hardware and the availability of the computer room. Except for School D where the computers were well-maintained and managed by an efficient IT person, the technical issues impeded the teachers in Schools A and B from using *BioLogica* effectively in their teaching in the way they wished. Even in School C, there were always in each class a few girls whose laptop computers were not working properly or had been sent away for repair.

In this study, the teachers also were teaching genetics with other resources (7) which included the use of audiovisual aids, models and other multimedia on human and molecular genetics (in School C only). These other resources must be considered as instrumental in contributing to student learning of genetics (15, 16 and 17). During the genetics unit for three to eight weeks, students (except those in School B who used *BioLogica* once) interacted with the MERs when they were engaged in at least three *BioLogica* activities—*Introduction*, *Meiosis* and *Monohybrid* (8). However, the level of engagement across Schools A, C and D varied from low to high as discussed in various parts of the thesis. Many students were intrinsically and/or extrinsically motivated (9) because of their personal interests (4) and the salient features of *BioLogica* (11), particularly visualisation and instant feedback afforded by *BioLogica* (see section 9.1.8). These salient features of the software constituted the situational interests of the students (2). The classroom interactions (12) also had important influence on students' learning with *BioLogica* MERs. In particular, useful classroom interactions are peer support (13) including collaboration or peer tutoring (see Chapter 7), and teachers' scaffolding (14) afforded to the students during their use of *BioLogica* activities. As discussed in various results chapters, the learning outcomes in this case study are considered along three dimensions—motivational outcomes (15) in terms students' enjoyment in their

[30] The number refers to the oval *Teacher's Beliefs and Referents (1)* in Figure 9.3.

learning, epistemological outcomes in terms of the six types of genetics reasoning (16) which students utilised in solving problems of genetics, and ontological conceptual change in terms of their understanding of the gene as a process as well as an active particle (17). Overall, students' conceptual learning was interpreted within these three perspectives.




*Arrows 18, 19 and 20 denote respectively the three functions of MERs—*to complement*, *to constrain* and *to construct* (Ainsworth, 1999))

*Figure 9.3* Causal network model for teaching and learning with MERs.

As for the functions of MERs, I argue here that the three functions of MERs were supporting student learning to different extents and towards conceptual change in learning genetics. The first function of MERs—to provide complementary information or processes (18)—is related more closely to students' motivational outcomes (15) and the increase in the status of the intelligibility (I) of their gene conceptions. Similarly, the second function—to constrain interpretation or misinterpretations of phenomena (19)—is related more closely to genetics reasoning and to the increase in the status of intelligibility and plausibility (IP) of their new conceptions. Finally, the third function of MERs—to encourage construction of deeper understanding (20)—is more related to the ontological conceptual change (17) which increases the status of intelligibility, plausibility and fruitfulness (IPF) of their conceptions. However, the relationships are assumed to be nonlinear and interwoven into a complex network (see Figure 9.3).

Further to the discussion of the teachers' PCK and the PCK-TT model (see Figure 9.2) in the preceding section, the following parts of the network from Figure 9.3 show the role of teachers' PCK in the integration and implementation of *BioLogica* in their teaching. Teacher's beliefs and referents (1) can be considered as their PCK that is connected to their understanding of students' prior knowledge (3), interests (2 and 4), and the salient features of *BioLogica* (11) and technical issues (5) and how the activities are selected, sequenced and implemented in the teaching (6 and 8) and integrated with other resources (7).

After all, this causal network in Figure 9.3 with the corresponding narrative in the section that followed is only my constructed abstraction of the previous chapters and sections. However, the network is systematically constructed based on *grounded theory* (Strauss & Corbin, 1998) (see section 3.4) in which the theories were derived from data and their analyses across the four cases and their embedded cases in several layers (a case school, case classes and case teachers/students). In generating this causal network for the study as a single case, I have juxtaposed the method, data collection, analyses, and theories to one another. Readers of this thesis can make their own interpretation of the overall findings and the judgement about the transferability of the findings to other situations of similar contexts.

## 9.2 Conclusions

Using Miles and Huberman's (1994) methods, the section concludes the thesis by summarising the overall findings in a synthesis of those assertions from the various chapters, generating the implications from the findings, suggesting some directions for further research, and ending the conclusions by a summary of the limitations of the study.

### 9.2.1 Overall Findings

The overall findings of this study in the form of general assertions are generated from the assertions from the results chapters and the cross-case analyses chapter. The general assertions are organised under the initial six research questions as headings. When a general assertion is generated from a specific research question of a particular case study, this will be mentioned alongside the general assertion. The analysis in Table 9.7 shows the relation between the specific research questions in each of the four case studies and the six initial research questions with comments on their differences.

The initial research questions from section 3.5 are copied below again for easy reference:

RQ1. How does the teacher integrate and implement *BioLogica* in his/her classroom teaching of genetics?

RQ2. What are the teacher's beliefs, referents, and actions in the integration and implementation of *BioLogica*?

RQ3. What are the major barriers to using *BioLogica* activities in classroom teaching?

RQ4. What are the factors from the social/affective perspective that influence students' interaction with *BioLogica* in their conceptual learning of genetics?

Table 9.7

*Matrix Comparing and Contrasting the Initial and Case-specific Research Questions*

| Initial Research Questions | Case-specific Questions (section) | | | |
|---|---|---|---|---|
| | Case Study One (4.1.1 ) | Case Study Two (5.2.1) | Case Study Three (6.1.1) | Case Study Four (7.1.1) |
| RQ1 | RQ4.1 | | RQ6.1 | RQ7.1 (To support students with low prior knowledge) |
| RQ2 | RQ4.2 | RQ5.2 | RQ6.2 | RQ7.2 |
| RQ3 | RQ4.3 | RQ5.3 | | |
| RQ4 | RQ4.4 | | RQ6.4 (MERs in other online multimedia | RQ7.3 |
| RQ5 | RQ4.5 (Conceptual change: epistemological dimension) | | | RQ7.4 (Learning and regular use of *BioLogica*) |
| RQ6 | RQ4.6 (Conceptual change: ontological dimension) | | | RQ7.5 (Learning related to MER functions) |
| | RQ4.7 (Relationship between gene conception and reasoning) | RQ5.1 (Teacher's PCK) | RQ6.3 (Factors affecting student-MERs interactions) | |
| | | RQ5.4 (Preservice teacher's conceptual change) | RQ6.5 (3-dimensional conceptual change in a laptop school compared to School A, a non-laptop school) | RQ7.6 (3-dimensional conceptual change after the *BioLogica* experience) |

RQ5. Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? If so, to what extent and in which types of genetics reasoning?

RQ6. What are the students' gene conceptions before and after the lessons that include *BioLogica*?

#### *9.2.1.1 Integration and Implementation of BioLogica*

This section is the overall findings in response to the initial research question 1: How does the teacher integrate and implement *BioLogica* in his/her classroom teaching of genetics?

*General Assertion 1*

*The teachers incorporated BioLogica in their teaching to suit their classroom context and as an aid to their teaching based on their beliefs and expectations about normal classroom practice.*

The five teachers integrated and implemented *BioLogica* differently in their own classrooms. Except for Miss Bell, the other four teachers each had much control over how many activities and how often their students would use the software. Whereas Mr Anderson used *BioLogica* as a supplement, Miss Bell used it to help students understand better as she felt insecure about her lack of teaching experience. Unlike Ms Claire and Mrs Dawson, who used *BioLogica* to accommodate the diversity of learning styles, Ms Elliott used it as an integral part of her teaching to engender understanding of her students, particularly those with lower interest and prior knowledge, and to prepare them for public examinations. The way in which the teachers incorporated the computer program in their teaching reflected their school context and all except Ms Elliott considered *BioLogica* as a teaching aid just like a video, overhead projection or any other sources. Strictly speaking, only Ms Elliott in School D fully integrated *BioLogica* in her teaching. As such, *incorporation* better describes the actions of the teachers than does *integration* in the research question.

*General Assertion 2*

*Teacher knowledge about the computer program BioLogica is crucial to its implementation for teaching of genetics and for the kind of scaffolding which the teachers afford the students working through the BioLogica activities.*

The common expectation of the five teachers who implemented *BioLogica* in their teaching was to motivate students in their learning. Perhaps only Miss Bell and Ms Elliott appreciated some functions of MERs, without using the jargon, because they knew the program best, having tried out the activities. The idiosyncratic ways in which the teachers incorporated *BioLogica* in their teaching also reflected their pedagogical content knowledge (PCK) (Shulman, 1986). Data from multiple sources indicated that all four experienced teachers had very good content knowledge of genetics, they knew their students quite well and had a good general pedagogical knowledge—the components of PCK. The only difference in the teacher's PCK within the special context of this study was their familiarity with the *BioLogica* program. It was this critical difference that enabled Ms Elliott to design an appropriate learning environment using the *BioLogica* activities she carefully selected, sequenced, paced and scaffolded for her two classes of differing interests and prior knowledge, particularly in ways to support the students in the Human Biology class. This finding about teachers' PCK is related to their beliefs and referents that guided their actions.

#### *9.2.1.2 Teachers' Beliefs, Referents and Actions*

This section is the overall findings in response to the initial research question 2: What are the teacher's beliefs, referents, and actions in the integration and implementation of *BioLogica*?

*General Assertion 3*

*The teachers' actions in implementing BioLogica in the classroom—preparing, planning, teaching and scaffolding—were underpinned by their own beliefs in teaching in general; their common beliefs about the usefulness of BioLogica were based on the salient features of the program rather than on the functions of MERs.*

As discussed in the section 9.1, the findings from Case Study Two suggested that the teachers' beliefs and referents underpinning their actions indirectly affected their PCK in the special context of this study (see section 5.8 and Figure 5.5). In the results chapters, I have analysed the transcripts of teacher interviews and lessons and other sources of data. Although the teachers were busy, those who believed that *BioLogica* was useful for teaching and learning of genetics committed more time and energy in trying out the software; in doing so, they acquired more knowledge about *BioLogica*. As General Assertion 2 states, teacher knowledge is crucial to the implementation and scaffolding of students' use of the computer-based activities in learning genetics. The teachers' actions in teaching with *BioLogica* also were shaped by their beliefs and what referents they used in their actions. Piagetian ideas might underpin Mr Anderson's action in using *BioLogica* as a supplement to motivate his students and provide them with drill and practice of what he had taught in class. The beliefs of Ms Claire and Mrs Dawson were different in that they intended to use *BioLogica* to provide another new opportunity for the girls with different learning styles. Their referents for their actions were probably similar to the ideas of multiple intelligences (Gardner, 1993). Ms Elliott's actions indicated that she used a social constructivist referent for her actions.

The common belief in the usefulness of *BioLogica* among all the teachers was about the salient features of visualisation and instant feedback. Except for Miss Bell and probably Ms Elliott, the teachers did not express any beliefs in how interactive multimedia can support learning or about multiple representations. I conjecture that Ms Claire and Mrs Dawson were more likely to use the metaphor of student as scientist as another referent for their actions in teaching.

#### *9.2.1.3 Major Barriers in Using BioLogica*

This section attempts to answer the third initial research question 3: What are the major barriers to using *BioLogica* activities in classroom teaching?

*General Assertion 4*

*When a teacher decided to use BioLogica in his or her teaching, technical issues and the kind of institutional support affected teaching and learning with BioLogica.*

When each of the teachers agreed to use activities from *BioLogica* in his or her teaching, the major barriers to their implementation came from the technical issues and/or the kind of IT support available in the school. Technical issues were unexpectedly found in School C where some of the student-owned laptop computers did not work or ran too slowly, resulting in both teachers and students becoming frustrated. Institutional factors also affected how the teachers in Schools A and B could better use *BioLogica* in teaching but these are not general findings. In Chapter 4, we have seen how Mr Anderson became frustrated when he could not install the software. In School B, the barrier appeared to be institutional rather than technical but this may not be typical as Miss Bell was a practising preservice teacher in the school. Teachers in Schools C and D had good institutional support, being provided with a laptop by their schools.

#### *9.2.1.4 Motivational Learning Outcomes*

Student motivation in learning with *BioLogica* and its MERs is the theme of this section. The overall findings in this section are the responses to the initial research question 4: What are the factors from the social/affective perspective that influence students' interaction with *BioLogica* in their conceptual learning of genetics?

*General Assertion 5*

*The MERs of BioLogica appeared to be intrinsically motivating for most students who were interested in genetics; most students' and teachers' views were congruous in believing that visualisation and instant feedback enhanced understanding.*

As discussed in section 9.1.10, most students already interested in genetics (personal interests) are likely to find the *BioLogica*'s salient features (situational interests) intrinsically motivating. Two salient features which were unanimously identified by both the teachers and the students─visualisation and instant feedback of the manipulable features of the MERs─were perceived to be useful for facilitating understanding by most students and all teachers. As discussed in section 9.1.8, visualisaton and instant feedback of the MERs in *BioLogica* contributed to their two functions—to provide complementary information or processes and to constrain interpretation (misinterpretation) of the phenomena of genetics.

However, when students, particularly those in School C, preferred real-life human examples to the *BioLogica* Dragons in learning genetics (see Figure 6.3), they might have displayed lower intrinsic motivations for engaging in the *BioLogica* activities using Dragon as context (see Table 6.4). As such, those students were unable to benefit from the constraining function of MERs in *BioLogica* when learning genetics.

#### *9.2.1.5 Genetics Reasoning and Conceptual Learning*

This section attempts to answer the initial research question 5: Do students improve their genetics reasoning before and after the lessons that include *BioLogica*? If so, to what extent and in which types of genetics reasoning?

*General Assertion 6*

*Most students improved their genetics reasoning after instruction by following a general pattern in which process reasoning between generations (Type VI) appeared to be more difficult than cause-to-effect reasoning within generation (Type I) and effect-to-cause reasoning between generations (Type IV).*

I generated General Assertion 6 based on Assertions 4.6 and 6.4 (see sections 4.4.2.2 and 6.4.2.2) on the pattern of genetics reasoning developed by students in School A and then consistently found in Schools C and D. Most students across the three schools and across the Year levels found Type VI reasoning more difficult than Types I, III and IV reasoning (see Figure 8.1). This general assertion does not constitute a new finding in this study but further corroborates other previous studies as meiosis is one of the most difficult topics for students studying biology (see for example, Hackling & Treagust, 1984; Kindfield, 1994; Longden, 1982; Stewart et al., 1990; Venville, 1997). Therefore, it is not considered a significant finding for this study. However, General Assertion 7 is a new finding about the role of mindfulness in meaningful interactions with the MERs of *BioLogica* to provide a plausible explanation for those students who did not improve genetics reasoning despite active engagement in the *BioLogica* activities.

General Assertion 7 also was generated in response to specific research question 6.3: What are the major factors affecting the students' interactions with the multiple representations?

*General Assertion 7*

*For those students who were actively engaged in BioLogica activities, some were able to construct their understanding but not others; mindfulness appeared to* *provide a plausible explanation for meaningful interaction with the MERs of BioLogica.*

Learning outcomes based on preinstructional-postinstructional improvement in genetics reasoning in the online tests and interview tasks in Schools A, C and D indicated that active engagement is not enough for cognitive learning. Such learning outcomes also were related to how students could transfer their learning from those computer activities to tests. For those students who were actively engaged in *BioLogica* activities, some were able to construct their understanding but others were not. Mindfulness (Salomon & Globerson, 1987) (see sections 2.3.12, 9.1.5 and other sections) appeared to provide a plausible explanation for meaningful interaction with the MERs that facilitates cognitive learning. The data analyses and interpretations—of log files collated with dialogic interaction transcripts—in School D provided strong evidence supporting this assertion; however, in other case studies, where the log files were not available, the evidence is weak.

#### *9.2.1.6 Ontological Conceptual Change*

The last section of overall findings addresses the initial research question 6: What are the students' gene conceptions before and after the lessons that include *BioLogica*?

*General Assertion 8*

*Most of the students' gene conceptions changed from a gene as an inactive particle to an active particle but their postinstructional gene conceptions were not sophisticated.*

General Assertion 8 came from the within-case (Tables 4.5, 6.8 and 7.9) and cross-case analyses (Table 8.3) which suggested that very few Year 10 students conceptualised the gene as a process after instruction, despite this topic having been taught, for example, in School C. The Year 12 students, too, appeared to focus on the gene as a particle that they used in reasoning and solving genetics problems.

In the fourth case study, the specific research question 7.6 sought a response about students' conceptual change after instruction: Have students undergone a three-dimensional conceptual change after the *BioLogica* experience? In response to this specific research question, I generated the last general assertion for this study.

*General Assertion 9*

*Most students had undergone conceptual change along the motivational and epistemological dimensions but only a very few students exhibited change along the ontological dimension. When students exhibited ontological change, such change was generally within the category of matter.*

When conceptual change is interpreted from a multidimensional framework, the students in this study did have conceptual change along the social/affective dimension in terms of their motivation and interest in learning genetics, and along the epistemological dimension in terms of their genetics reasoning, but not along the ontological dimension. As analysis and interpretation of data from multiple sources indicated, there was little or no evidence for conceptual change across ontological categories in the students' gene conceptions. A few students like Andrea of School C—where the teacher taught about DNA functions—did show some across-category ontological change. She developed a sophisticated gene conception by drawing on her prior knowledge and she worked through several *BioLogica* activities in a mindful way.

Instruction including the use of *BioLogica* did not appear to bring about conceptual change across ontological categories in School A. This was, however, consistent with the teacher's teaching and the *BioLogica* activities selected for the student use. Classroom observations showed that Mr Anderson did not explicitly mention about the function of DNA when teaching about the gene. Nor did he encourage his students to use the *BioLogica* activity *Mutations* which provides students with a DNA Tool with which users can both view and change the base sequence of the DNA molecule and observe the change in corresponding phenotype of the Dragon. As previous research has indicated, students' development of a sophisticated gene conception or conceptual change across ontological categories appeared not to be in evidence in Western Australian Year 10 science (Hackling & Treagust, 1984; Venville & Treagust, 1998). This study shows that this situation has not changed during the past two decades.

*9.2.1.7 Summary of Major Findings*

This section summarises the major findings of the study on the basis of the nine general assertions together, in parentheses, with the initial or case-specific research question(s) to which each finding provides a response or part of a response (also see section 9.2.1 and Table 9.7):

1. Teachers idiosyncratically incorporated *BioLogica* activities in their classroom teaching based on their beliefs and referents for their actions as in normal classroom teaching (RQ1 and RQ2)

2. Teachers' implementation and their scaffolding of student learning with *BioLogica* were affected by their knowledge of the software and beliefs about its usefulness based on the salient features of MERs rather than their functions (RQ1, RQ2 and RQ5.1).

3. Implementation of *BioLogica* in teaching also was affected by institutional support, technical issues, and time constraints (RQ3).

4. Most students were motivated and enjoyed learning with *BioLogica* but not all who were actively engaged in the activities improved their genetics reasoning (RQ4, RQ5 and RQ7.4)

5. Mindfulness (Salomon & Globerson, 1987) in learning with the MERs of *BioLogica*, learning together with peers and scaffolded learning within the zone of proximal development (Vygotsky, 1978) are important to students' conceptual learning (RQ6.3 and RQ7.1).

6. The postinstructional gene conceptions of most students were not sophisticated (Venville & Treagust, 1998) and were generally intelligible-plausible (IP) but not intelligible-plausible-fruitful (IPF) (Thorley, 1990) (RQ5 and RQ6).

7. Whereas most students identified two salient features of *BioLogica* MERs, visualisation and instant feedback, some students who substantially improved

their reasoning believed that these two features helped their understanding of genetics (RQ4, RQ6.3 and RQ7.5).

8. Overall, students exhibited social/affective (motivational) and epistemological conceptual change but little or no ontological change (RQ4, RQ5, RQ6, RQ6.5 and RQ7.6).

### 9.2.2 Implications

The findings of this study based on the initial research questions and on some specific research questions in the four case studies give rise to a number of implications for theory and practice related to science education, educational psychology and cognitive/computational sciences.

#### *9.2.2.1 Multidimensional CCM and Thorley's Status*

The findings of this study show that Thorley's (1990) framework for analysing the status of conceptions is robust and could be used by researchers in determining students' conceptual change learning. Although the status elements (see Table 2.3) in his framework are largely epistemological, they also encompass the other two dimensions in Tyson et al.'s (1997) multidimensional conceptual change model. In this study, many students claimed that they enjoyed learning and understood genetics with the *BioLogica* Dragons. Their conceptions were intelligible according to Thorley's status elements for intelligibility such as INTELLIGIBILITY ANALOGY and IMAGE or LANGUAGE. Such motivational aspects of their learning are in keeping with Tyson et al.'s social/affective dimension. When students like Helena talked about her conception of genetics—that genetics would not be of much use to her after the TEE but it would be so for her classmate Paul because he wanted to study medicine (see Table 8.11)—the status element PROMISE is useful in determining whether Helena's conception is fruitful. Again this is similar to Tyson et al.'s social/affective dimension of conceptual change. As for the ontological dimension, Thorley's plausibility status element METAPHYSICS (adopted from Posner et al., 1982) explicitly refers to the ontological status of objects or beliefs.

#### *9.2.2.2 MERs Provide New Learning Opportunities and New Challenges for Teachers*

The finding that teachers' actions in using *BioLogica* were based on their beliefs and referents for normal classroom teaching has implications for using ICT in teaching science in Australian schools. MERs-rich interactive programs such as *BioLogica* may provide new learning opportunities for students but also give rise to new challenges for teachers.

The findings in this study indicated that the role of the teacher appeared to be a critical determinant in supporting student learning with MERs, although, in many ways, the teachers still had the mindset of teaching in a normal, non-ICT-supported classroom. This implication is consistent with Windschitl and Sahl's (2002) assertion that the ubiquity of computers in schools has not initiated teachers towards more constructivist instruction. There is much to be done for teacher educators in this area. Two implications are discussed here.

First, teaching for conceptual change is not easy, particularly for a difficult topic like genetics. Therefore, it would be more useful, although not possible in this naturalistic study, if the teachers had more time for teaching the topic and engaging their students more frequently in interacting with the MERs of the *BioLogica* activities. Over a longer period of teaching and learning, students may be able to better develop their conceptual understandings of genetics and more likely to transfer their reasoning for problem solving from one context to another. This implication will be incorporated in the further research in section 9.2.3.1. Second, Australian science teacher educators should highlight pedagogical content knowledge (PCK) related to teaching with ICT (Friedrichsen et al., 2001) (see section 5.1). Both inservice and preservice teacher education courses about teaching with ICT should include an introduction to MERs with software examples such as *BioLogica*. In section 9.1.11, I proposed the *PCK-TT model* (see section 9.1.11) which is an amalgam of theories from several areas whose intersection is central to this kind of special pedagogical content knowledge (PCK) for teachers in the information age. This proposed model can be one possible basis for developing teacher education programs to encourage teaching science with technology for conceptual change.

#### *9.2.2.3 Urgency of Teaching Gene/DNA Functions in Year 10 Science*

The findings of this study show that most Year 10 students, after a course of instruction in genetics, had not conceptualised the gene as being part of a DNA molecule coded for the protein structure.

I contend that teachers should teach the importance of this understanding which was celebrated by scientists, in April 2003, with the golden anniversary of the discovery of the double helix of DNA (Watson & Crick, 1953b). In this study, most of the Year 10 students did not develop sophisticated postinstructional gene conceptions—a situation similar to the findings of Venville and Treagust's (1998) study of genetics education in Western Australia. Without understanding the gene functions in controlling protein synthesis or Type V genetics reasoning, students' gene conceptions cannot be fruitful and be capable of understanding of genetics for a layperson in the 21st century. For example, after learning genetics, Year 10 students should be able to understand why the successful mapping of the genome of the deadly *SARS* [31] virus is the key to developing a vaccine or a remedy for the disease.

Furthermore, the teaching of DNA functions can provide a very useful context for students to learn about the values and morals related to genetics. Students cannot make informed decision without the knowledge about DNA functions at a time when genetically modified foods, genomics or cloning are frequently the controversial topics of debate in the media. In my opinion, it is urgent that all Year 10 science classes in Western Australian schools should be taught about DNA functions as in School C. Lastly, although the five teachers in this study, except Mrs Dawson (see Appendix 1, Table A1.6.2), did not spend much time discussing with the students the ethical and moral implications of DNA technology, they should be aware that such a discussion can be a motivator in teaching genetics in the classroom.

[31] *Severe Acute Respiratory Syndrome (SARS)*—caused by a deadly coronavirus never seen in humans—was believed to have originated from southern China in November 2002. SARS was rapidly transmitted through air travellers to other parts of the world. By 25 April 2003, SARS had killed 276 and infected 4642 in 27 countries and had not been effectively controlled (CNN, 2003b).

#### *9.2.2.4 Functions of MERs Unify Several Areas of Learning*

The findings about student learning with *BioLogica* indicate that the functions of multiple external representations (MERs) (Ainsworth, 1999) constitute a useful theoretical framework for unifying several areas of research—educational psychology, cognitive/computational sciences, conceptual change learning in science education and teacher education. This framework is useful for analysing, interpreting, reporting, communicating and improving science education with or without computers.

The notion of multiple representations also can enable teachers to improve their normal classroom teaching using different representations and to optimise students' learning by harnessing the possible pedagogical functions of different representations. The proposed PCK-TT model is an attempt in this direction to effectively provide a robust framework for science teacher professional development in order to teach more effectively in a multi-representational learning environment with or without computers.

#### *9.2.2.5 Teaching to Enhance Intentional Learning*

Throughout the thesis, I have touched on intentional learning (Bereiter & Scardamalia, 1989) and intentional conceptual change (Sinatra & Pintrich, 2003b)—the new trend in learning and instruction. Although I did not use this as a focus of my study, themes that emerged from all the four case studies have implications of the how teachers can encourage students to set intentional learning as goal in their learning. In particular, a few Year 10 students in Ms Elliott's Human Biology class of School D such as Helena (see section 8.3.7), appeared to be an intentional learner who had developed her understanding through her interaction with *BioLogica* MERs. I will suggest a further study based on this implication in one of the following section (see 9.2.3

### 9.2.3 Suggestions for Further and Future Research

The implications in the preceding sections can be directions for further and future research with *BioLogica* or similar programs.

When a future study involves a larger sample of students using *BioLogica* or other ICT programs, we can explore the classroom perceptions using a questionnaire alongside the three methods of data collection—interviews, observations and document/artefact analyses. The new questionnaire *Technology-Rich Outcome-Focused Learning Environment Inventory (TROFLEI)* (Aldridge, Fraser, Fisher, & Wood, 2002), developed in our education centre, is a suitable candidate in this regard in the suggested further studies to be described in the next sections. The outcomes of the following suggested projects may inform the development of a new scale about MERs to be added in TROFLEI.

#### *9.2.3.1 Teaching for Conceptual Change and Thorley's (1990) Status Analysis*

One future research project using *BioLogica* or other hypermodels is to explore status-related interactions in technology-rich classrooms using Thorley's (1990) *status analysis categories* and how such interactions can contribute teaching for conceptual change (Hewson, 1996; Hewson, Beeth, & Thorley, 1998; Hewson & Thorley, 1989).

In this naturalistic study, no agendas were imposed on the teachers' teaching except that they agreed, in some ways as conveniently possible, to include *BioLogica* in their genetics course. However, teachers in the future studies may be encouraged to teach for conceptual change with the instructional strategies suggested by researchers (Hewson, 1996; Hewson et al., 1998) in ICT-rich learning environments. As already discussed in 9.2.2.2, it would also be more useful if the study had been extended over a longer period of time for the students to better develop their conceptual understanding from their interactions with the *BioLogica* MERs.

#### *9.2.3.2 Scaffolding Students' Learning within their Zone of Proximal of Development*

Another suggested further research is on scaffolding students' learning in a *BioLogica* learning environment within their *zone of proximal development* (Vygotsky, 1978). Despite the success of some studies using Vygotsky's sociocultural perspective in reading research such as *reciprocal teaching* (Palinscar & Brown, 1984) or mathematics education (see for example, Cobb, 1998; Ireland, 2000), the influence on research in science education is still not extensive (Hodson &

Hodson, 1998; Howe, 1996). Several aspects in the findings of this study—peer support or tutoring and scaffolded learning—warrant further investigation.

#### *9.2.3.3 Student Metacognitive, Metaconceptual and Intentioanl Learning*

In section 2.2.6.2, I discussed Thorley's (1990) construct of *metaconceptual learning* which is related to *metacognition* in conceptual learning. It is about "reflection of the content of conceptions themselves, for example, considering why a learner regards a particular phenomenon as a force" (Thorley, 1990, p. 116). Exploration of students' metaconceptual learning can be a useful research agenda using *BioLogica* or other interactive multimedia programs in conceptual change teaching and learning because this is about another uncharted area of research. Furthermore, this also is related to *intentional conceptual change* (Sinatra & Pintrich, 2003b)—a new direction in conceptual change research. It follows that a further study on *BioLogica* or other MERs-rich computer multimedia can focus on how teachers enhance intentional learning of their students towards conceptual change.

#### *9.2.3.4 Teachers' PCK for Teaching Science with Technology*

The last suggested further research is based on the findings of the second case study in School B and the proposed *PCK-TT model* in section 9.1.11. As reviewed in Chapter 5, research into teacher knowledge, particularly teacher's pedagogical content knowledge (PCK) has recently become popular in Australia but there is a gap in the kind of PCK needed by teachers in teaching science with ICT similar to Friedrichsen's (2001) notion and the PCK-TT model. The findings in School B about Miss Bell's expansion of her PCK could inform a future study in the future with a larger sample of participating preservice teachers using *BioLogica* or other hypermodels in their practice teaching. The study also could investigate how preservice teachers understand the pedagogical use of multimedia in terms of the three functions of MERs which researchers claim to support learners by providing complementary information and process, by constraining interpretation of phenomena, and by fostering the construction of deeper understanding (Ainsworth, 1999). Such a study would be expected to contribute to the development of science teacher education programs in the information age.

## 9.3 Summary of Limitations

I have discussed the limitations of this research in an overview of the study (Chapter 1), in the methodology chapter (Chapter 3) and in each of the four case studies in the results chapters (Chapters 4 to 7). In this section, I summarise these ideas and synthesise them into the overall limitations of the study as a single case vis-à-vis the overall findings of the study. The case-based interpretive research approach—based on a core framework of the multidimensional conceptual change—has its inherent methodological limitations according to Merriam (1998) (see section 3.10). In retrospect, three of those limitations that are most relevant to this study are rephrased and discussed in this section using the limitations in the individual case studies to illustrate each. The fourth and fifth limitations have emerged from the individual case studies.

First, there was the possibility of oversimplification or exaggeration of the situation in the four case studies leading to conclusions that do not adequately represent reality. Reporting by narrative stories and analytic vignettes in various results chapters may not fully describe and explain what was actually happening in the classroom. *Member checking* (Guba & Lincoln, 1989) by the protagonists can be useful to match the constructed reality to the reality. Unfortunately, I was only able to have feedback from Miss Bell on a draft of Chapter 5 about her. This lack of member checking imposed a limitation on the use of the narratives in reporting the findings of this study.

Second, the overall findings of this research study may have limitations due to the lack of representativeness of both the selected cases and of the data collected about these cases. In this study, the method in selecting cases—schools, teachers and students—was based on convenient and purposeful sampling (Patton, 1990) in keeping with the qualitative research tradition. The samples of interviewees in each classroom also might not be representative because they were selected on the basis of the students' pretest scores and their wish to participate. The cross-case comparison of the findings in Schools A, C and D was less useful for understanding learning at the Year 10 level compared to students at School D who were from the Year 12 classes.

Third, there may be insufficient rigour due to the researcher's bias or subjectivity of others involved in this case study. I have disclosed my own philosophical orientations and my impaired hearing. The latter did affect the quality of observational and interview data, although the helpers (see section 1.6 and footnote 2) transcribed the interview and lesson audio-recordings and came twice to each classroom to observe the lessons in order to be more conversant with each classroom context. As already discussed in section 3.8, although three types of triangluation were used to increase rigour and credibility of the findings, a fourth type of triangulation—investigator triangulation (Denzin, 1989)—was technically not possible for this study. Given that I was the only observer and coder of the transcribed data and online postings, there was inevitably bias in my data interpretations. However, I had used most strategies such as peer debriefing and member checking to address this limitation.

Fourth, the data collection was sometimes incomplete. For example, in the second case study in School B, there were no opportunities available to collect data about students' learning outcomes. In Schools A and C, the incomplete set of log files being collected imposed limitations on the findings about student learning from the *BioLogica* activities.

A fifth limitation is related to the time constraints. The teachers were too busy to engage in more extensive and fruitful conversations with me during my school visits to enable me to better understand their views and gain feedback about my comments. Sometimes, I wished to ask them some more questions after the classroom observations but they were too busy or too tired to talk to me. Ms Elliott was more willing to discuss briefly with me after the lessons compared to the other teachers. However, all teachers except Mrs Dawson always responded to my e-mail questions.

Overall, the challenge of qualitative research was and still is, as Miles and Huberman (1984) said in the first edition of their book, that "we have few agreed-on canons for qualitative data analysis, in the sense of shared rules for drawing conclusions and verifying their sturdiness" (p. 16). Since then, the methods of qualitative research have made great strides in improving the rigour of the design and analysis as I have described and discussed in Chapter 3 and in various places in the results chapters and the cross-case analyses chapter. I used many of such techniques, particularly triangulations, to increase the rigour of this study. In this chapter, I have tried to use some of the Miles and Huberman's tactics to draw and verify the conclusions. I also have provided rich and thick descriptions throughout this thesis so that readers of different backgrounds may make their own interpretations of my results and they may or may not arrive at the same conclusions. Such a situation is in keeping with the notion of transferability (Guba & Lincoln, 1989) for my findings to be applied for use in some other situations with similar contexts.

## 9.4 Finale

As final remarks in this thesis, I must say, based on the study that I am not convinced that Australian schools have improved the quality of science education since Queensland's *SUNRISE Project* about teaching and learning with personal computers in 1991 (Rowe, 1993). Ten years on, my two-year classroom experiences working in four different Western Australian schools—including one of the most high-achieving independent laptop schools and three state schools with quite different contexts—have not convinced me that the teachers effectively utilised the latest generation of computers or the available information and communication technologies (ICT) to enhance student learning for understanding. My convictions in this regard are not new as both Australian researchers (see for example, Newhouse & Rennie, 2001; Stolarchuk & Fisher, 2001) and international researchers (see for example, Poole, 2000; Windschitl & Sahl, 2002) held similar views based on their research. On the basis of the limited sample reported in this thesis, I believe that teachers are still not as well prepared as they could be for using ICT in teaching science for understanding.

It is interesting to think of Poole's (2000) metaphor of "a long gestation" (p. 209) to describe the use of ICT in science education in the UK by quoting a report which concluded with the statement "the state of ICT in our schools is primitive and not improving" (p. 209). Poole suggested three major reasons for this: (1) ICT is expensive and is still not well resourced in most schools; (2) Most science teachers are not well trained in the use of ICT at the professional level; and (3) Most science teachers remain unconvinced about the effectiveness of ICT in improving the performance of students. Whereas the first reason may be true for School A but certainly not for Schools C or D, the second and third reasons appear to be not much different across all the schools where the teachers are very experienced but have not been formally educated, as far as I know, to use ICT in their teaching.

It would be useful now for teachers to know about and understand the possible functions of multiple external representations (MERs) or multiple representations in order to make better pedagogical decisions and subsequent use of ICT in the classroom. I believe that this study—in which teachers incorporated the new software *BioLogica* into their lessons to varying degrees—has made some small contributions to science education in general and to Australian science education using technology in particular.

# Epilogue

The rigour of a qualitative study depends on the human factor. However, the qualitative researcher should sense a paradox in which "[the] human factor is the great strength and the fundamental weakness of qualitative inquiry and analysis" (Patton, 1990, p. 372). When I finally completed my thesis, Patton's comment appealed to me in a new way: "[t]he analysis of qualitative data is a creative process… also a process demanding intellectual discipline, analytical rigor, and a great deal of hard work" (p. 381). Indeed, I worked very hard and became tired. I think that I have tried my possible best in conducting this study in the belief that this study may make a small but significant contribution to science education.

On reflection, I had an arduous but exciting journey over the past three years. Besides having travelled in my car for about four thousand kilometres during the one hundred or so visits to the case schools, I spent hundreds of hours at the school sites to an extent beyond my anticipation. Then, I think of the vehicle—not just the metaphor of the *BioLogica* Dragon being a vehicle for constraining interpretation but also my own real vehicle—which is so important to me when I consider research as a journey. When I first discussed with Professor David Treagust about my research proposal at the end of 2000, I remember the very first question he asked me was about whether I had a car. I didn't, I said, but I had been driving for many years and I would have one soon if I wanted to conduct research in schools. In retrospect, just like the metaphor of research as a journey I mentioned in the Prologue, the vehicle played an important role metaphorically and literally in conducting this multiple-case research. No other times were so distressing, when, during my data collection in School C, about 20 km from our university, my car broke down for a week. A half-a-hour journey by car to the school needed two hours commuting by bus or train. Once, I missed a lesson of Ms Claire that I planned to observe.

Perhaps Yin (1994) was right when he advised lone researchers against undertaking a multiple-case research design because of the huge demand on time and energy. I took this risk in cherishing the opportunity of having more rigour in the study without heeding the expert advice. Readers of this thesis can also imagine the extra effort and energy which a hearing-impaired researcher needed in completing this study. Fortunately, with the support of the Curtin University of Technology, my supervisor, colleagues, and friends, and, of course, the participating teachers and students, I was able to complete the study in four case schools. The fruitfulness in completing this study and the valuable experiences of working with the participating teachers and students were worth the time, energy and funds invested on the study.

Over my two years of researching in the six classrooms across four schools, I found that it was always a privilege to work with the five participating teachers and their students, most of whom warmly supported my research in the belief that we all may benefit in the process in one way or another. I most enjoyed working in School D. On the last day in School D, I sent Ms Elliott and her students a box of chocolates to say thank you to them. The next day, Ms Elliott e-mailed me about one student who wished to see me. The student went to the school library—where I used to stay before and after classroom observation—trying to find me, but I was gone. As I would never return to the school again after the research, I just wished the student the best in her TEE when I replied to Ms Elliott's e-mail message. Over the subsequent months, as I read the transcripts and re-listened to the tapes, the power and the promise voiced by the students in School D enabled me to conjure up the images of Ms Elliott and her students in the classroom. As I analysed and interpreted the data, I tried to think of these students in terms of their pseudonyms as reported in my thesis but their real names came to my mind. The most rewarding moment of my study was to know that many students enjoyed their learning with *BioLogica* and some became more confident in their learning when they demonstrated that they had made substantial improvement over their own knowledge baseline.

# References

AARE. (1993, 20/09/1989). *Ethics and educational research* [A web-based edited book]. Australian Association for Research in Education. Retrieved 3 March, 2003, from the World Wide Web: http://www.aare.edu.au/index.htm

Ainsworth, S., Bibby, P. A., & Wood, D. J. (1998). Analysing the costs and benefits of multi-representational learning environments. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 120-134). London: Elsevier Science.

Ainsworth, S. E. (1999). The functions of multiple representations. *Computers & Education, 33*(2/3), 131-152.

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1997). Information technology and multiple representations: New opportunities - new problems. *Journal of Information Technology for Teacher Education, 6*(1), 93-104.

Aldridge, M. J., Fraser, B. J., Fisher, D. L., & Wood, D. (2002). *Assessing students' perceptions of outcome-focused technology-rich learning environments.* Paper presented at the annual meeting of the American Educational Research Association (AERA), New Orleans, USA.

Anderton, J. (Ed.). (1990). *Fundamentals of science: Book 4*. Melbourne, Australia: Longman Cheshire Pty Limited.

Andre, T., & Windschitl, M. (2003). Interest, epistemological belief, and intentional conceptual change. In G. M. Sinatra, & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 173-197). Mahwah, NJ: Lawrence Erlbaum Associates.

Atkinson, J. W., & Raynor, J. O. (Eds.). (1974). *Motivation and achievement*. Washington: Winston.

Ausubel, D. (1968). *Educational psychology : A cognitive view*. New York: Holt, RineHart & Winston, Inc.

Bahar, M., Johnstone, A. H., & Hansell, M. H. (1999). Revisiting learning difficulties in biology. *Journal of Biological Education, 33*(2), 84-86.

Bell, B., Osborne, R., & Tasker, R. (1985). Finding out what children think (Appendix A). In R. Osborne, & P. Freyberg (Eds.), *Learning in science*. Auckland: Heinemann.

Bereiter, C., & Scardamalia, M. (1989). Intentional learning as a goal of instruction. In L. B. Resnick, et al. (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 361-392). Hillsdale, NJ: Lawrence Erlbaum Association.

Beyerbach, B., Christie, W., & Vannatta, R. (2001). From teaching technology to using technology to enhance student learning: Preservice teachers' changing perception of technology infusion. *Journal of Technology and Teacher Education, 9*(1), 105.

Bliss, J. (1995). Piaget and after: The case of learning science. *Studies in Science Education, 25*, 139-172.

Borg, W. R., Gall, J. P., & Gall, M. D. (1993). *Applying educational research*. New York: Longman.

Bowler, P. J. (1989). *The Mendelian revolution*. Baltimore, MD: John Hopkins University Press.

Buckley, B. C. (2001). *Making sense of data logs with the MV data*.Unpublished manuscript.

Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.

Carey, S. (1986). Cognition science and science education. *American Psychologist, 41*(10), 1123-1130.
Carr, W., & Kemmis, S. (1986). *Becoming critical: Education, knowing, and action research*. London: Falmer Press.
Carter, G., Westbrook, S. L., & Thompkins, C. D. (1999). Examining science tools as mediators of students' learning about circuits. *Journal of Research in Science Teaching, 36*(1), 89-105.
Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Learning and Instruction, 8*, 293-332.
Chi, M. T. H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. N. Giere (Ed.), *Cognitive models of science* (pp. 129-186). Minneapolis: University of Minnesota Press.
Chi, M. T. H. (1997). Quantifying qualitative analysis of verbal data: A practical guide. *The Journal of the Learning Sciences, 1*(69-105).
Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*, 27-43.
Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*(1), 1-49.
Christie, M. A., & Buckley, C. B. (2001). *BioLogica research* [Website]. Concord Consortium. Retrieved 5 September 2001, 2001, from the World Wide Web: http://biologica.concord.org/webtest1/biologica_research.htm
Christie, M. A., & Horwitz, P. (in progress). *Instructional design for understanding*. Concord consortium. Retrieved 18 January, 2002, from the World Wide Web: http://biologica.concord.org/webtest1/IDfU.htm
CNN. (2003a). *Scientists map suspected SARS virus genome*. CNN. Retrieved 18 April, 2003, from the World Wide Web: http://edition.cnn.com/2003/HEALTH/04/14/sars.sequence/index.html
CNN. (2003b). *Special report: SARS virus on the move*. CNN. Retrieved 25 April, 2003, from the World Wide Web: http://edition.cnn.com/SPECIALS/2003/sars/index.html
Cobb, P. (1998). *Analysing the mathematical learning of the classroom community: The case of statistical data analysis.* Paper presented at the Proceedings of the 22nd Conference of the International Group for the Psychology of Mathematics Education, Stellenbosch, South Africa.
Cold Spring Harbour Laboratory. (2002). *Your Genes, Your Health* [Onlinie multimedia]. Dolan DNA Learning Center. Retrieved 14 August 2002, 2002, from the World Wide Web: http://www.ygyh.org/
Concord Consortium. (2001, October). *BioLogica*. Concord Consortium. Retrieved October 8, 2001, from the World Wide Web: http://biologica.concord.org
Concord Consortium. (2002, October). *BioLogica guide* [PDF File]. Concord Consortium. Retrieved June, 2002, from the World Wide Web: http://mac.concord.org/downloads/
Cox, R., & Brna, P. (1995). Supporting the use of external representations in problem solving: The need for flexible learning environments. *Journal of Artificial Intelligence in Education, 6*(2/3), 239-302.
Crick, F., & Koch, C. (2002). The problem of consciousness. *Scientific American (Special Edition), 12*(1), 10-17.

Crook, C. (1994). *Computers and the collaborative experiences of learning*. London: Routledge.
Csikszentmihalyi, M. (1975). *Beyond boredom and anxiety*. San Francisco: Jossey-Bass.
Csikszentmihalyi, M. (1992). *Flow: The psychology of happiness*. London: Rider.
Curriculum Council. (1998). *Curriculum framework for kindergarten to Year 12 in Western Australia*. Perth: Curriculum Council of Western Australia.
Damon, W., & Phelps, E. (1989). Critical distinctions among three approaches to peer education. *International Journal of Educational Research, 13*, 9-19.
Darden, L. (1991). *Theory change in science: Strategies from Mendelian genetics*. New York: Oxford University Press.
Darden, L. (1992). Strategies for anomaly resolution. In R. N. Giere (Ed.), *Cognitive models of science* (pp. 251-273). Minneapolis, MN: University of Minnesota.
Darwin, C. (1859). *The origin of species* (1st ed.). London: Penguin (reprinted and edited).
Davidson, J. E., & Sternberg, R. J. (1985). Competence and performance. In R. Neimark, R. De Lisi, & J. L. Newton (Eds.), *Moderators of competence* (pp. 43-76). Hillsdale, NJ: Erlbaum.
de Jong, T. Ainsworth, S. Dobson, M. van der Hulst, A. Levonen, J., et al. (1998). Acquiring knowledge in science and mathematics: The use of multiple representations in technology-based learning environments. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 9-40). London: Elsevier Science.
Dekeyser, H. M. (2001). Student preference for verbal, graphic or symbolic information in an independent learning environment for an applied course. In J.-F. Rouet, J. Levonen, & A. Biardeau (Eds.), *Multimedia learning*. Amsterdam: Pergamon.
Denzin, N., & Lincoln, Y. S. (Eds.). (1994). *Handbook of qualitative research*. Thousand Oaks, CA: Sage.
Denzin, N. K. (1989). *The research act: A theoretical introduction to sociological methods*. Englewood Cliffs, NJ: Prentice Hall.
Dienes, Z. (1973). *The six stages in the process of learning mathematics*. Windsor: NFER.
Dillenbourg, P. (1996). Distributed cognition over humans and machines. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the design of technology-supported learning environments* (pp. 165-183). Mahwah, NJ: Lawrence Erlbaum Associates.
diSessa, A. A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10*(2 & 3), 105-225.
Dixon, J. K. (1997). Computer use and visualisation in students' construction of reflection and rotation concepts. *School Science and Mathematics, 97*(7), 352-358.
Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.
Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61-84.
Duit, R. (1999). Conceptual change approaches in science education. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 263-282). London: Pergamon.

Duit, R., & Glynn, S. (1996). *Mental modelling*. In G. Welford, J. Osborne, & P. Scott (Eds.), *Research in science education in Europe: Current issues and themes* (pp. 166-176). London, UK: The Falmer Press.

Duit, R., & Treagust, D. F. (1998). Learning in science: From behaviourism towards social constructivism and beyond. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 3-25). Dordrecht, The Netherlands: Kluwer.

Education Department of Western Australia. (1987). *The unit curriculum: Science (science and technology)*. Perth: Education Department of Western Australia.

Education Department of Western Australia. (1998). *Outcomes and standards framework: Student outcome statements (science)*. Perth, Western Australia: Education Department of Western Australia.

English, L. D. (1997). Analogies, metaphors, and the images: Vehicles for mathematical reasoning. In L. D. English (Ed.), *Mathematical reasoning: Analogies, metaphors and images* (pp. 3-18). Mahwah, NJ; London: Lawrence Erlbaum Associates.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. Wittrock (Ed.), *Handbook of research on teaching* (pp. 119-161). New York: Macmillan.

Erickson, F. (1998). Qualitative research methods for science education. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 1115-1173). Dordrecht, The Netherlands: Kluwer.

Fensham, P. J., Gunstone, R. F., & White, R. T. (Eds.). (1994). *The content of science: A constructivist approach to its teaching and learning*. London; Washington, D.C.: Falmer Press.

Ferrari, M., & Elik, N. (2003). Influences on intentional conceptual change. In G. M. Sinatra, & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 21-54). Mahwah, NJ: Lawrence Erlbaum Associates.

Fisher, R. A. (1936). *Has Mendel's work been rediscovered?* Mendelweb. Retrieved 31 December, 2002, from the World Wide Web: http://www.mcn.org/c/irapilgrim/men01.html

Fraser, B. J., & Tobin, K. G. (1991). Combining qualitative and quantitative methods in classroom environment research. In B. J. Fraser, & H. J. Walberg (Eds.), *Educational environments: Evaluation, antecedents and consequences* (pp. 271-291). London: Pergamon.

Friedel, A. W., Gabel, D. L., & Samuel, J. (1990). Using analogs for chemistry problem solving: Does it increase understanding? *School Science and Mathematics, 90*(8), 674-682.

Friedrichsen, P. M., Dana, T. M., Zembal-Saul, C., Munford, D., & Tsur, C. (2001). Learning to teach with technology model: Implementation in secondary teacher education. *Journal of Computers in Mathematics and Science Teaching, 20*(4), 377-395.

Gahan, C. (1998). *Doing qualitative research using QSR NUD.IST*. London: Sage.

Gallagher, J. J. (Ed.). (1991). *Interpretive research in science education* (Vol. 4). Manhattan, KS: National Association for Research in Science Teaching (NARST), Kansas State University.

Gardner, H. (1993). *Multiple intelligences: The theory in practice*. New York: Basic Books.

Gentner, D., & Gentner, D. R. (1983). Flowing water and teeming crowds: Mental models of electricity. In D. Gentner, & A. L. Stevens (Eds.), *Mental models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum Associates Publishers.

Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability and metacognition. *Educational Research, 42*(2), 119-139.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-17). Dordrecht: The Netherlands: Kluwer.

Gibbs, G. R. (2002). *Qualitative data analysis: Exploration with NVivo*. Buckingham; Philadelphia: Open University Press.

Giere, R. N. (1984). *Understanding scientific reasoning* (2nd ed.). New York: Holt, Rinehart and Winston.

Giere, R. N. (1991). *Understanding scientific reasoning* (3rd ed.). Fort Worth, TX: Holt, Rinehart and Winston.

Giunchiglia, F., & Walsh, T. (1992). A theory of abstraction. *Artificial Intelligence, 57*(325-289).

Glaser, B. R., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.

Glaser, R., Ferguson, E. L., & Vosniadou, S. (1996). Introduction: Cognition and the design of environments for learning. In S. Vosniadou, E. De Corte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the design of technology-supported learning environments* (pp. 1-9). Mahwah, NJ: Lawrence Erlbaum Associates.

Glynn, S. M. (1991). Explaining science concepts: A teaching-with-analogies model. In M. Shawn, S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 219-240). Hillsdale, N.J: Lawrence Erlbaum Associates.

Griffard, P. B., & Wandersee, J. H. (2001). The two-tier instrument on photosynthesis: what does it diagnose? *International Journal of Science Education, 23*(20), 1039-1052.

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Guba, Y., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Newbury Park, CA: Sage.

Hackling, M. W., & Treagust, D. F. (1984). Research data necessary for meaningful review of grade ten high school genetics curricula. *Journal of Research in Science Teaching, 21*(1), 197-209.

Harrison, A., & Treagust, D. (2001). Conceptual change using multiple interpretive perspectives: Two cases studies in secondary school chemistry. *Instructional Science, 29,* 45-85.

Harrison, A. G. (1996). *Conceptual change in secondary chemistry: The role of multiple analogical models of atoms and molecules.* Unpublished PhD thesis, Curtin University of Technology, Perth, Australia.

Harrison, A. L., & Treagust, D. F. (1993). Teaching with analogies: A case study in grade-10 optics. *Journal of Research in Science Teaching, 30*(10), 1291-1307.

Haslam, F., & Treagust, D., F. (1987). Diagnosing secondary students' misconceptions and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education, 21*(3), 203-211.

Henderson, J., & Wellington, J. (1998). Lowering the language barrier in learning and teaching science. *School Science Review, 79*(288), 35-46.

Henig, R. M. (2000). *The monk in the garden: The lost and found genius of Gregor Mendel, the father of genetics*. Boston; New York: Houghton Mufflin.

Hennessy, S. Twigger, D. Driver, R. O' Shea, T. O' Shea, T., et al. (1995). Design of a computer-augumented curriculum for mechanics. *International Journal of Educational Research, 17*(1), 75-92.

Hewitt, S. (2003, January 17). Girls top class: Private schools dominate. *The West Australian*, pp. 1, 8.

Hewson, P. (2002, August). *Thorley's analysis of status: The hallmark of conceptual learning.* Paper presented at the Seminar at the Science and Mathematics Education Centre, Curtin University of Technology, Perth, Australia.

Hewson, P., & Lemberger, J. (2000). Status as the hallmark of conceptual learning. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 110-125). Buckingham UK; Philadelphia, PA: Open University Press.

Hewson, P. W. (1981). A conceptual change approach to learning science. *European Journal of Science Education, 3*(4), 383-396.

Hewson, P. W. (1982). A case study of conceptual change in special relativity: The influence of prior knowledge in learning. *European Journal of Science Education, 4*(1), 79-94.

Hewson, P. W. (1996). Teaching for conceptual change. In D. F. Treagust, R. Duit, & B. J. Fraser (Eds.), *Improving teaching and learning in science and mathematics* (pp. 131-140). New York: Teachers College Press.

Hewson, P. W., Beeth, M. E., & Thorley, N. R. (1998). Teaching for conceptual change. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 199-218). Dordrecht, The Netherlands: Kluwer.

Hewson, P. W., & Hennessey, M. G. (1992). Making status explicit: A case study of conceptual change. In H. Niedderer, F. Goldberg, & R. Duit (Eds.), *Research in physics learning: theoretical issues and empirical studies* (pp. 176-187). Kiel, Germany.

Hewson, P. W., & Hewson, M. G. A. B. (1992). The status of students' conceptions. In H. Niedderer, F. Goldberg, & R. Duit (Eds.), *Research in physics learning: Theoretical issues and empirical studies* (pp. 59-73). Kiel, Germany: Institute for Science Education at the University of Kiel.

Hewson, P. W., & Thorley, N. R. (1989). The conditions of conceptual change in the classroom. *International Journal of Science Education, 11*, 541-553.

Hickey, D. T. (1997). Motivation and contemporary socio-constructivist instructional perspectives. *Educational Psychologist, 32*(3), 175-193.

Hickey, D. T., & Kindfield, A., C. H. (1999, April). *Assessment-oriented scaffolding of student and teacher performance in a technology-supported genetics environment.* Paper presented at the annual meeting of the American Educational Research Association, Montreal, Canada.

Hiebert, J., & Carpenter, T. P. (1992). Learning and teaching with understanding. In D. A. Grouws (Ed.), *Handbook of Research in Mathematics Teaching and Learning* (pp. 65-97). New York: Macmillan.

Hodson, D., & Hodson, J. (1998). From constructivism to social constructivism: A Vygotskian perspective on teaching and learning science. *School Science Review, 79*(289), 33-41.

Horwitz, P. (1999). *Turning information into knowledge: Hypermodel for science education: Final report submitted to National Science Foundation Education and Human Resources Directorate* (Grant # RED-955343). Concord, MA: The Concord Consortium.

Horwitz, P., & Christie, M. T. (2000). Computer-based manipulatives for teaching scientific reasoning: An example. In M. J. Jacobson, & R. B. Kozma (Eds.), *Innovations in science and mathematics education: Advanced design for technologies of learning* (pp. 163-191). Hillsdale, NJ: Lawrence Erlbaum Associates.

Horwitz, P., & Tinker, R. (2001). Pedagogica to the rescue: A short history of hypermodels. *Concord Newsletter, 5*(1), 1-4.

Horwood, R. H. (1988). Explaining and description in science teaching. *Science Education, 72*(1), 41-49.

Howe, A., C. (1996). Development of science concepts within a Vygotskian framework. *Science Education*, *80*(1), 35-51.

Hoz, R., Tomer, Y., & Tamir, P. (1990). The relations between disciplinary and pedagogical knowledge and the length of teaching experience of biology and geography teachers. *Journal of Research in Science Teaching, 27*(10), 973-985.

Huff, A. S. (1999). *Writing for scholarly publication*. Thousand Oaks, CA: Sage.

Ireland, D. V. (2000). *The implementation of a collaborative peer interactive mathematics classroom learning environment.* Unpublished PhD thesis, Curtin University of Technology, Perth, Australia.

Jacobson, M. J., & Kozma, R. B. (Eds.). (2000). *Innovations in science and mathematics education: Advanced designs for technologies of learning*. Mahwah, NJ: Lawrence Erlbaum Associates.

Johnson-Laird, P. N. (1983). *Mnetal models*. Cambridge: Cambridge University Press.

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning, 7*, 75-83.

Johnstone, A. H., & Mahmoud, N. A. (1980). Isolating topics of high perceived difficulty in school biology. *Journal of Biological Education*, *12*(2), 163-166.

Jonassen, D. H. (2000). *Computers as mindtools for schools: Engaging critical thinking*. Upper Saddle River, NJ: Prentice-Hall Inc.

Jonassen, D. H. (2001). How can we learn best from multiple representations? *The American Journal of Psychology, 114*(2), 321-327.

Jones, C. (2000). The role of language in the learning and teaching of science. In J. Osborne (Ed.), *Good practice in science teaching* (pp. 89-103). Buckingham; Philadelphia: Open University Press.

Jungck, J., & Calley, J. (1985). Strategic simulations and post-Socratic pedagogy: Constructing computer software to develop long-term inference through experimental inquiry. *The American Biology Teacher, 47*, 11-15.

Keil, F. (1989). *Concepts, kinds, and cognitive development*. Cambridge, MA: MIT Press/Bradford Books.

Kindfield, A. C. H. (1992, March). *Teaching genetics: Recommendations and research.* Paper presented at the Teaching Genetics: Recommendations and Research Proceedings of a National Conference, Cambridge, Massachusetts, USA.

Kindfield, A. C. H. (1994). Assessing understanding of biological process: Elucidating students' models of meiosis. *The American Biology Teacher, 56*(6), 367-371.

Kindfield, A. C. H., & Hickey, D. T. (1999, April 19-23). *Tools for scaffolding inquiry into the domain of introductory genetics.* Paper presented at the annual meeting of the American Educational Research Association, Montreal.

Kinnear, J. (1986). Using the Domestic Cat in the Teaching of Genetics. *Journal of Biological Education, 20*(1), 5-11.

Kozma, R. B. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomenon. *Journal of Research in Science Teaching, 34*(9), 949-968.

Kozma, R. B. (2000). The use of multiple representations and the social construction of understanding in chemistry. In M. J. Jacobson, & R. B. Kozma (Eds.), *Innovations in science and mathematics education: Advanced design for technologies of learning* (pp. 11-46). Mahwah, NJ: Lawrence Erlbaum Associates.

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning and development. In K. A. Renninger, S. Hidi, & A. Krapp (Eds.), *The role of interest in learning and development* (pp. 3-25). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kuhn, T. S. (1970). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lakatos, I. (1970). Falsification and the methodology of science research programmes. In I. Lakatos, & A. Musgrave (Eds.), *Criticism and the growth of knowledge* (pp. 91-196). Cambridge: Cambridge University Press.

Lankshear, C., Snyder, I., & Green, B. (2000). *Teachers and technoliteracy*. Sydney, NSW: Allen & Unwin.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65-99.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lawless, K. A., Smith, E. V., Kulikowich, J. M., & Owen, S. V. (2001). Preservice teachers' beliefs about the relationships between domain knowledge and instructional media. *International Journal of Instructional Media, 28*(3), 261-270.

Leask, M., & Pachler, N. (Eds.). (1999). *Learning to teach using ICT in the secondary school*. London; New York: Routledge.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.

Lemke, J. L. (1998a). Analysing verbal data: Principles, methods and problems. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 1175-1189). Dordrecht, The Netherlands: Kluwer.

Lemke, J. L. (1998b). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. R. Martin, & R. Veel (Eds.), *Reading science* (pp. 87-113). London: New York: Routledge.

Lemonick, M. D. (2003, February 17). A twist of fate. *Time,* 43-52.

Lewis, J., Leach, J., & Wood-Robinson, C. (2000). Chromosomes: The missing link--young people's understanding of mitosis, meiosis, and fertilisation. *Journal of Biological Education, 34*(4), 189-199.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills , CA: Sage.

Lohse, G. L., Biolsi, K., Walker, N., & Rueler, H. H. (1994). A classification of visual representations. *Communications of the ACM, 37*(12), 36-49.

Longden, B. (1982). Genetics-are there inherent learning difficulties? *Journal of Biological Education, 16*(2), 135-141.

Loughran, J., Milroy, P., Berry, A., Gunstone, R., & Mulhall, P. (2001). Documenting science teachers' pedagogical content knowledge through PaP-eRs. *Research in Science Education, 31*, 289-307.

Loughran, J., Mitchell, I., Neale, R., & Toussant, D. (2001). PEEL and the beginning teacher. *Australian Educational Researcher, 28*(2), 29-52.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. Snow, & M. Farr (Eds.), *Aptitude, learning, and instruction: Vol. 3 Cognitive and affective process analyses* (pp. 223-253). Hillsdale, NJ: Erlbaum.

Markham, K. M., Mintzes, J. J., & Jones, M. G. (1994). The concept map as a research and evaluation tool: Further evidence of validity. *Journal of Research in Science Teaching, 31*(1), 91-101.

Martins, I., & Ogborn, J. (1997). Metaphorical reasoning about genetics. *Internatioanl Journal of Educational Research, 19*(6), 48-63.

Mathison, S. (1988). Why triangulate? *Educational Researcher, 17*(2), 13-17.

Matthews, M. R. (1998). *Constructivism in science education: A philosophical examination*. Dordrecht, The Netherlands ; Boston: Kluwer Academic.

Mayer, R. E., & Moreno, R. (2002). Aids to computer-based multimedia learning. *Learning and Instruction, 12*(1), 107-109.

Mendel, G. (1865a). *Experiments in plant hybridization*. Mendelweb. Retrieved 31 December, 2002, from the World Wide Web: http://www.mendelweb.org/Mendel.html

Mendel, G. (1865b). *Versuche über Pflanzen-Hybriden*. Mendelweb. Retrieved 31 December, 2002, from the World Wide Web: http://www.mendelweb.org/Mendel.html

Merriam, S. B. (1988). *Case study research in education*. San Francisco: Jossey-Bass Publishers.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass Publishers.

Miles, M. B., & Huberman, A. M. (1984). *Qualitative data analysis: A sourcebook of new methods*. Thousand Oaks, CA: Sage.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (Second ed.). Thousand Oaks, CA: Sage.

Monaghan, J. M., & Clement, J. (2000). Algorithms, visualisation, and mental models: High school students' interactions with a relativity simulation. *Journal of Science Education and Technology, 9*(4), 311-325.

Monk, M. (1995). What do epistemology and ontology have to offer in considering progression in physics education? In B. C., C. Tarsitani, & M. Vincentini (Eds.), *Thinking physics for teaching* (pp. 127-137). New York: Plenum Press.

Morange, M. (2001). *The misunderstood gene*. Cambridge MA: Harvard University Press.

Morgan, T. H. (1926). *The theory of the gene*. New Haven: Yale University Press.
Morgan, T. H., Sturtevant, A. H., Müller, H. J., & Bridges, C. B. (1915). *The mechanism of Mendelian heredity*. New York: Henry Holt and Company.
Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 21-50). Dordrecht: The Netherlands: Kluwer.
Natural History Museum. (2002). *Dinosaurs* [Museum exhibit]. London: The Natural History Museum.
Newhouse, P., & Rennie, L. (2001). A longitudinal study of the use of student-owned portable computers in a secondary school. *Computers & Education, 36*(2001), 223-243.
Novak, J. D. (1978). An alternative to Piagetian psychology for science and mathematics education. *Studies in Science Education, 5*, 1-30.
Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching, 27*, 937-949.
Novak, J. D. (1996). Concept mapping: A tool for improving science teaching and learning. In D. F. Treagust, R. Duit, & B. J. Fraser (Eds.), *Improving teaching and learning in science and mathematics* (pp. 32-43). New York: Teachers College Press.
Novak, J. D. (1998). *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations*. Mahwah, NJ: Lawrence Erlbaum Associates.
Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York: Cambridge University Press.
Odom, A. L., & Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching, 32*(1), 45-61.
Ogborn, J., Kress, G., Martin, I., & McGillicuddy, K. (1996). *Explaining science in the classroom*. Buckingham: Open University Press.
Olby, R. C. (1997). *Mendel, mendelism, and genetics*. MendelWeb. Retrieved 31 December, 2002, from the World Wide Web: http://www.mendelweb.org/archive/MWolby.txt
Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart and Winston, Inc.
Paivio, A. (1986). *Mental representation and dual coding approach*. New York: Oxford University Press.
Palinscar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and comprehension monitoring activities. *Cognition and Instruction, 1*, 117-175.
Pankratius, W. J. (1990). Building an organised knowledge base: Concept mapping and achievement in secondary school physics. *Journal of Research in Science Education, 27*(4), 315-333.
Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Newbury Park, CA: Sage.
Pearson, J. T., & Hughes, W. J. (1988a). Problems with the use of terminology in genetics education: 1. A literature review and classification scheme. *Journal of Biological Education, 22*(3), 178-182.

Pearson, J. T., & Hughes, W. J. (1988b). Problems with the use of terminology in genetics education: 2. some examples from published materials and suggestions for rectifying the problem. *Journal of Biological Education, 22*(4), 267-274.

Pintrich, P. R. (1999). Motivational beliefs as resources for and constraints on conceptual change. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 33-50). Amsterdam; Oxford: Pergamon.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.

Pintrich, P. R., & Schrauben, B. (1992). Students' motivational beliefs and their cognitive engagement in classroom academic tasks. In D. H. Schunk, & J. L. Meece (Eds.), *Student perceptions in the classroom* (pp. 149-183). Hillsdale, NJ: Lawrence Erlbaum Associates.

Polya, G. (1954). *Mathematics and plausible reasoning, Vol. 1: Induction and analogy in mathematics*. Princeton, NJ: Princeton University Press.

Poole, P. (2000). Information and communications technology in science education: A long gestation. In J. Sears, A. Smith, & P. Sorensen (Eds.), *Issues in science teaching* (pp. 209-218). London and New York: RoutledgeFalmer.

Pope, M., Hare, D., & Howard, E. (2002). Technology integration: Closing the gap between what preservice teachers are taught to do and what they can do. *Journal of Technology and Teacher Education*, *10*(2), 191-203.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211-227.

Putnam, R. T., & Borko, H. (1997). Teacher learning: Implications of new views of cognition. In B. J. Biddle, T. L. Good, & I. F. Goodson (Eds.), *International handbook of teachers and teaching* (pp. 1223-1296). Dordrecht, The Netherlands: Kluwer.

Rennie, L. J., Fraser, B. J., & Treagust, D. F. (1999). Research into science education. In J. Keeves, & K. Marjoribanks (Eds.), *Australian Education: Review of Research 1965-1998* (pp. 171-203). Melbourne: Australian Council for Educational Research.

Resnick, L., & Omanson, S. (1987). Learning to understand arithmetics. In R. Glaser (Ed.), *Advances in instructional psychology volume 3* (pp. 41-95). Hillsdale, NJ: Erlbaum.

Ridgway, J. (1996). *Vygotsky, informatics capability, and professional development.* Paper presented at the IFIP TC3 WG3.1/3.5 Joint Working Conference on Information Technology : Supporting Change Through Teacher Education, Kiryat Anavim, Israel.

Rohr, M., & Reimann, P. (1998). Reasoning with multiple representations when acquiring the particulate model of matter. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 41-66). London: Pergamon.

Roth, W.-M., & Tobin, K. (2001). Learning to teach science as practice. *Teaching & Teacher Education, 17,* 741-762.

Rowe, H. A. H. (1993). *Learning with personal computers: Issues, observations and perspectives*. Hawthorne, Australia: Australian Council for Educational Research.

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching, 33*(6), 569-600.

Russell, P. J. (2002). *iGenetics*. San Francisco: Benjamin Cummings.

Rye, J. A., & Rubba, P. A. (1998). An exploration of the concept map as an interview tool to facilitate the externalization of students' understandings about global atmospheric change. *Journal of Research in Science Teaching, 35*(5), 521-546.

Salomon, G. (1979). *Interaction of media, cognition, and learning*. San Francisco, CA: Jossey-Bass.

Salomon, G., & Globerson, T. (1987). Skill may not be enough: The role of mindfulness in learning and transfer. *International Journal of Educational Research, 11*(6), 623-637.

Schwedes, H., & Schmidt, D. (1991). Conceptual change: A case study and theoretical comments. In R. Duit (Ed.), *Research in physics learning: theoretical issues and empirical studies* (pp. 188-202). Kiel, Germany: Institute for Science Education at the University of Kiel.

Sfard, A. (1991). On the dual nature of mathematical conceptions: reflections on processes and objects as different sides of the same coin. *Educational Studies in Mathematics, 22*, 1-36.

Shapiro, B. (1998). Reading the furniture: The semiotic interpretation of science learning environment. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 609-621). Dordrecht, The Netherlands: Kluwer.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundation of the new reform. *Harvard Educational Review, 57*(1), 1-22.

Simmons, P. E., & Lunetta, V. N. (1987). Catlab: A learning cycle approach. *The American Biology Teacher, 49*, 107-109.

Simon, E. J. (2001). Technology instead of a textbook: alternatives for the introductory biology classroom. *The American Biology Teacher, 63*(2), 89-94.

Sinatra, G. M., & Pintrich, P. R. (2003a). The role of intentions in conceptual change learning. In G. M. Sinatra, & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 1-18). Mahwah, NJ: Lawrence Erlbaum Associates.

Sinatra, G. M., & Pintrich, P. R. (Eds.). (2003b). *Intentional conceptual change*. Mahwah, NJ: Lawrence Erlbaum Associates.

Sinclair, J. M., & Coulthard, R. M. (1975). *Towards an analysis of discourse: the English used by teachers and pupils*. London: Oxford University Press.

Skemp, R. R. (1976). Relational understanding and instrumental understanding. *Mathematics Teaching, 77*, 20-26.

Smith, E. L. (1991). A conceptual change model of learning science. In S. M. Glynn, B. R. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 45-63). Hillsdale, N.J: Lawrence Erlbaum Associates.

Smith, K. B. (1997). Exploration and visualisation: Making critical connections about linear systems of equations. *School Science and Mathematics*, *97*(1), 13-19.

Spada, H. (1994). Commentary: Conceptual change or multiple representations. *Learning and Instruction, 4*, 113-116.

Spiro, R. J., & Jehng, J. (1990). Cognitive flexibility and hypertext: Theory and technology for the non-linear and multidimensional traversal of complex subject matter. In D. Nix, & R. Spiro (Eds.), *Cognition, education, multimedia: Exploring ideas in high technology* (pp. 163-205). Hillsdale, NJ: Lawrence Erlbaum.

Squires, D. (2000). *New teaching methods in science education: The role of new technologies.* Paper presented at the Teaching and Learning Science and Mathematics at the Information Age: Institute of Key Centre for School Science and Mathematics, Curtin University of Technology, Perth, Australia.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

Stewart, J., van Kirk, J., & Rowell, R. (1979). Concept maps: A tool for use in biology teaching. *The American Biology Teacher, 41*(3), 171-175.

Stewart, J. H. (1982). Difficulties experienced by high school students when learning basic Mendelian genetics. *The American Biology Teacher, 44*(2), 80-84, 89.

Stewart, J. H., Hafner, R., & Dale, M. (1990). Students' alternate views of meiosis. *The American Biology Teacher, 52*, 228-232.

Stolarchuk, E., & Fisher, D. (2001). First years of laptops in science classrooms results in more learning about computers than science. *Issues in Eduational Research, 11*(1), 25-39.

Strauss, A. L., & Corbin, J. (1998). *Basics of qualitative research: Grounded theory procedures and techniques* (2nd ed.). Thousand Oaks, CA: Sage.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl, & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). Albany: State University of New York Press.

Stuart, C., & Thurlow, D. (2000). Making it their own: Preservice teachers' experiences, beliefs, and classroom practice. *Journal of Teacher Education, 51*(2), 113-121.

Sutton, C. (1992). *Words, science and learning*. Buckingham UK; Philadephica PA: Open University Press.

Tao, P.-K., & Gunstone, R. F. (1999). Conceptual change in science through collaborative learning at the computer. *International Journal of Science Education, 21*(1), 39-57.

Taylor, P., . C. (1998). Constructivism: Value added. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook of science education* (pp. 1111-1123). Dordrecht, The Netherlands: Kluwer.

Taylor, P. C. (1993). Collaborating to construct teaching: The influence of researcher beliefs. In K. Tobin (Ed.), *The practice of constructivism in science education*. Washington DC: AAAS Press.

Thagard, P. (1988). *Computational philosophy of science*. Cambridge, MA: MIT Press.

Thagard, P. (1992a). Analogy, explanation, and education. *Journal of Research in Science Teaching, 29*(6), 537-544.

Thagard, P. (1992b). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.
Thomas, D. A., Johnson, K., & Stevenson, S. (1996). Integrated mathematics, science, and technology: An introduction to scientific visualisation. *Journal of Computers in Mathematics and Science Teaching, 15*(3), 267-294.
Thorley, N. R. (1990). *The role of the conceptual change model in the interpretation of classroom interactions.* Unpublished doctoral dissertation, University of Wisconsin-Madison, Wisconsin, USA.
Thorley, N. R., & Stofflett, R. T. (1996). Representation of the conception change model in science teacher education. *Science Education, 80*(3), 317-339.
Tobin, K. G. (1990). Social constructivist perspectives on the reform of science education. *The Australian Science Teachers' Journal, 36*(4), 29-35.
Tobin, K. G., & Fraser, B. J. (1998). Qualitative and quantitative landscapes of classroom learning environment. In B. J. Fraser, & K. G. Tobin (Eds.), *International handbook for science education* (pp. 623-640). Dordrecht, The Netherlands: Kluwer.
Toulmin, S. (1972). *Human understanding: An inquiry into the aims of science*. Princeton, NJ: Princeton University Press.
Treagust, D., F., Duit, R., Joslin, P., & Lindauer, I. (1992). Science teachers' use of analogies: Observations from classroom practice. *International Journal of Science Education, 14*(4), 413-422.
Treagust, D., F., Harrison, A. G., Venville, G. J., & Dagher, Z. (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education, 18*, 213-229.
Treagust, D., & Harrison, A. (1999). The genesis of effective scientific explanation. In J. Loughran (Ed.), *Researching teaching: Methodologies and practices for understanding pedagogy* (pp. 28-43). London; Philadelphia, PA: Falmer Press.
Treagust, D., Venville, G., Harrison, A., Stocklmayer, S., & Theile, R. (1994, July). *Using analogies in science teaching: A workshop presented at the annual meeting of the Australian Science Teachers' Association.* Paper presented at the CONASTA, Launeston, Western Australia.
Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconception in science. *International Journal of Science Education, 10*(2), 159-169.
Treagust, D. F. (2001, May). *Using analogies in science teaching to engender students' interest, motivation and understanding.* Paper presented at the Sixth Annual International Conference :Energising Science, Mathematics and Technical Education for All, Brunei Darussalam.
Treagust, D. F., Wilkinson, W. J., Leggett, M., & Glasson, P. (1991). Tolerance of ambiguity: A necessity for helping learners deal with novel tasks. In J. J. Gallagher (Ed.), *Interpretive research in science education* (Vol. 4, pp. 5-17). Manhattan, KS: NARST, Kansas State University.
Tsui, C.-Y. (1999, July). *Designing and developing computer-based worksheets in collaboration with biology teachers to scaffold classroom learning of genetics with GenScope.* Paper presented at the 30th annual conference of the Australasian Science Education Research Association (ASERA), Rotorua, New Zealand.

Tsui, C.-Y. (2000). *GenScope project: Learning genetics with computers in Year 12 biology* (Unpublished report in the Teacher Retraining Project 2000). Auckland, New Zealand: Auckland College of Education.

Tsui, C.-Y., & Treagust, D. F. (2003). Learning with computer dragons. *Journal of Biological Education, 37*(2), 96-98.

Tudge, C. (2000). *In Mendel's footnotes: An introduction to the science and technologies of genes*. London: Jonathan Cape.

Tyson, L. M., Treagust, D. F., & Bucat, R. B. (1999). The complexity of teaching and learning chemical equilibrium. *Journal of Chemical Education, 76*(4), 554-558.

Tyson, L. M., Venville, G. J., Harrison, A. L., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. *Science Education, 81*, 387-404.

van Someren, M. W., Boshuizen, H. P. A., de Jong, T., & Reimann, P. (1998). Introduction. In M. W. van Someren, P. Reimann, H. P. A. Boshuizen, & T. de Jong (Eds.), *Learning with multiple representations* (pp. 1-5). London: Elsevier Science.

van Someren, M. W., Reimann, P., Boshuizen, H. P. A., & de Jong, T. (Eds.). (1998). *Learning with multiple representations*. London: Pergamon.

Venville, G. J. (1997). *Secondary students' understanding of the gene concept: An analysis of conceptual change from multiple perspectives.* Unpublished PhD thesis, Curtin University of Technology, Perth, Australia.

Venville, G. J., & Treagust, D., F. (1996). The role of analogies in promoting conceptual change in biology. *Instructional Science, 24*, 295-320.

Venville, G. J., & Treagust, D., F. (1997). Analogies in biology education: A contentious issue. *The American Biology Teacher, 59*(5), 282-287.

Venville, G. J., & Treagust, D. F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching, 35*, 1031-1055.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction, 4*, 45-69.

Vosniadou, S. (1999). Conceptual change research: State of the art and future directions. In W. Schnotz, S. Vosniadou, & M. Carretero (Eds.), *New perspectives on conceptual change* (pp. 3-13). London: Pergamon.

Vosniadou, S. (2003). Exploring the relationships: Between conceptual change and intentional learning. In G. M. Sinatra, & P. R. Pintrich (Eds.), *Intentional conceptual change* (pp. 377-406). Mahwah, NJ: Lawrence Erlbaum Associates.

Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*, 51-67.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535-585.

Vosniadou, S., De Corte, E., Glaser, R., & Mandl, H. (Eds.). (1996). *International perspectives on the design of technology-supported learning environments*. Mahwah, NJ: Lawrence Erlbaum Associates.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*(4-5), 381-419.

Vygotsky, L. S. (1962). *Thought and language.* Cambridge, MA: The M.I.T. Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge MA: Harvard University Press.
Wallace, J., & Louden, W. (2000). *Teachers' learning: Stories of science education*. Dordrecht, The Netherlands: Kluwer.
Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching, 27*(10), 1033-1052.
Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177-210). New York: MacMillan Publishing Co.
Watson, J. D. (1968). *The double helix*. London: Penguin Books.
Watson, J. D. (2001). *A passion for DNA: Genes, genomes, and society*. New York: Cold Spring Harbor.
Watson, J. D., & Crick, F. H. C. (1953a). Genetical implications of the structure of deoxyribonucleic acid. *Nature, 177*, 964.
Watson, J. D., & Crick, F. H. C. (1953b). Molecular structure of nucleic acids: A structure of deoxyribose nucleic acid. *Nature, 171*, 737-738.
Werstch, J. V. (Ed.). (1985). *Culture, communication and cognition: Vygotskian perspectives.* Cambridge: Cambridge University Press.
Werstch, J. V., & Stone, C. A. (1985). The concept of internalization in Vygotsky's account of the genesis of higher mental functions. In J. V. Wertsch (Ed.), *Culture, communication and cognition: Vygotskian perspectives.* (pp. 163-179). Cambridge: Cambridge University Press.
Wertsch, J. V. (1991). *Voices of the mind: A sociocultural approach to mediated action*. London: Harvester Wheatsheaf.
WGBH. (2002). *DNA Workshop*. WGBH. Retrieved December 23, 2002, from the World Wide Web: http://www.pbs.org/wgbh/aso/tryit/dna/index.html#
White, R. (1997). Trends in research in science education. *Research in Science Education, 27*(2), 215-221.
White, R., & Gunstone, R. (1992). *Probing understanding*. London: The Palmer Press.
White, R. T. (1994). Commentary: Conceptual and conceptional change. *Learning and Instruction, 4*, 117-121.
White, R. T., & Gunstone, R. F. (1989). Metalearning and conceptual change. *International Journal of Educational Research, 11*, 557-586.
Windschitl, M., & Sahl, K. (2002). Tracing teachers' use of technology in a laptop computer school: The interplay of teacher beliefs, social dynamics, and institutional culture. *American Educational Research Journal, 39*(1), 165-205.
Wood, R. (1993). Taking the plunge into the gene pool: Teaching and learning in genetics. *Research in Science Education, 23*, 337-344.
Wood, R. (1996). *From my DNA to Darwin: Learning and teaching in genetics.* Unpublished D.Phil thesis, University of Waikato, Hamilton (New Zealand).
Wu, H.-K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualisation tool in the classroom. *Journal of Research in Science Teaching, 38*(7), 821-842.

Yeo, S., Loss, R., Zadnik, M., Harrison, A., & Treagust, D. F. (1998, April). *What do students really learn from interactive multimedia? A physics case study*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Yin, R. K. (1994). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

# List of Author's Presentations and Publications

# Related to this Thesis

**Tsui, C.-Y.** (2002a, November). *Learning with multiple representations in a technology-rich school: A case study in a Year 12 TEE class*. Paper presented at the 25th annual conference of the Western Australian Science Education Association (WASEA), Canning College, Perth, Western Australia.

**Tsui, C.-Y.** (2002b, September). *Teaching with multiple representations: An analysis of five science teachers' pedagogical content knowledge (PCK).* Paper presented at the Science and Mathematics Education Centre (SMEC) Seminar, Curtin University of Technology, Perth, Western Australia.

**Tsui, C.-Y.** (2003, February). *Using WebCT for research in WA schools*. Paper presented at the Third Annual WA WebCT Forum 2003, Curtin University, Perth, Western Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2001a, August). *Learning genetics with interactive multimedia: Year 10 students' voices.* Paper presented at the annual forum of the Western Australian Institute of Educational Research (WAIER), Edith Cowan University, Perth, Western Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2001b, December). *Teaching and learning reasoning in genetics with multiple external representations*. Paper presented at the annual meeting of the Australian Association for Research in Education (AARE), Fremantle, Western Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2001c, June). *Using interactive multimedia to teach genetics with understanding.* Paper presented at the 22nd Conference of the Science Teachers' Association of Western Australian (CONSTAWA 22), Muresk Institute of Agriculture, Northam, Western Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2002a, July). *Development of genetics reasoning with multiple representations: An ontological perspective.* Paper presented at the 33rd annual conference of the Australasian Science Education Association (ASERA), Townsville, Queensland, Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2002b, August). *Learning genetics with multiple representations: Preliminary findings in a laptop school.* Paper presented at the 17th Annual Research Forum of the Western Australian Institute for Educational Research (WAIER), Edith Cowan University, Perth, Western Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2002c). The monk in the garden: A book review. *SCIOS: the Journal of the Science Teachers' Association of Western Australia*, 38(1), 22-23.

**Tsui, C.-Y.**, & Treagust, D. F. (2002d, December). *A preservice science teacher's pedagogical content knowledge: The story of Linda.* Paper presented at the annual conference of the Australian Association for Research in Education (AARE), Brisbane, Australia.

**Tsui, C.-Y.**, & Treagust, D. F. (2002e, April). *Social/affective dimension in learning genetics with multiple representations in secondary biology.* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), New Orleans, USA.

**Tsui, C.-Y.**, & Treagust, D. F. (2003a, March). *Learning genetics with multiple representations: A three-dimensional analysis of conceptual change.* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Philadelphia, USA.

**Tsui, C.-Y.**, & Treagust, D. F. (2003b). Learning with computer dragons. *Journal of Biological Education*, 37(2), 96-98.

**Tsui, C.-Y.**, & Treagust, D. F. (2003c). Genetics reasoning with multiple external representations. *Research in Science Education*, 33, 111-135.

**Tsui, C.-Y.**, & Treagust, D. F. (in press). Motivational aspects of learning genetics with interactive multimedia. *The American Biology Teacher*.

# APPENDICES

# Appendex 1: Tables

## —Chronologies, Matrices of Data and Student Information

Table A1.4.1

*Chronology of Classroom Observation and Research Activities in School A*

| Date of Visit | Topic# in Observed Lessons/Tests | Other Activities/Remarks |
|---|---|---|
| 30 April 2001 | | See Principal/Mr Anderson to formalise participation |
| 3 May 2001 | Human reproductive systems | |
| 4 May 2001 | Gametes, fertilisation, embryo and faetology (sic) | |
| 7 May 2001 | | Discussion with Mr Anderson |
| 8 May 2001 | | Preinstrutional (Pre) interview with Mr Anderson |
| 10 May 2001 | Flower, fertilisation, adaptation | |
| 11 May 2001 | Cells, nucleus | |
| 17 May 2001 | DNA, growth and development, mitosis | |
| 18 May 2001 | PRETEST, *BioLogica* activity 'Introduction' | |
| 21 May 2001 | *BioLogica* activity 'Meiosis'* | Pre student Interview 1-1 |
| 22 May 2001 | | Pre student Interview 1-2 |
| 24 May 2001 | Teacher's 80 min test | Pre student Interview 1-3 |
| 28 May 2001 | Variation, sex inheritance, meiosis* | Observation with Megan (helper) |
| 29 May 2001 | | Collection of log files, Pre student interview 1-4, Worked with Mr Anderson using *BioLogica* |
| 31 May 2001 | Crosses introduction* | Observation with Megan |
| 1 June 2001 | *BioLogica* activity 'Monohybrid'* | Observation with Megan |
| 7 June 2001 | More crosses and monohybrid problems | |
| 8 June 2001 | Sex linkage and incomplete dominance | |
| 11 June 2001 | Pedigrees and their uses | |
| 12 June 2001 | | Student interviewees absent |
| 13 June 2001 | | Student interviewees absent |
| 14 June 2001 | | Postinstructional (post) student Interview 2-1 |
| 18 June 2001 | | Late for an interview |
| 19 June 2001 | | Post student interview 2-2 |
| 21 June 2001 | | Post student interview 2-3 |
| 25 June 2001 | POSTEST + good-bye to students | Post student interview 2-4 |
| 27 June 2001 | | Post interview with Mr Anderson |

# the names of the topics were based on Mr Anderson's planned schedule
*lessons video-taped

*Table A1.4.2*

*Analysis of the BioLogica Activity Monohybrid Data Log Files of Seven School A Students on 1 June 2001*

| | | | | | No. of Instances of Viewing Chromosomes of | | | | | | | | Number Of attempts | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Parent(s) Only | | | Gametes | | Offspring and /or Parents | | | | | | | | | | | | | | |
| NAME | Total Time (T) | Number of Interactions ( mouse clicks /other selections)(L) | Index of interaction (T/L) | Made a Baby Dragon Without Looking at Chromosomes | Both in Meiosis View | Pedigree View | Punnett Square | Meiosis View | Fertilisation View | Offspring and Parents in Meiosis View | Offspring in Pedigree View | Total Number of Viewings | Challenge 1:Make Plain-/Fancy-tailed Baby | Challenge 2:Create Zygotes in tt X Tt Punnett Square | Challenge 3:selct zygotes tt x Tt Punnett Square | Challenge 4: create gametes & zygotes in tt x TT Punnett Square | Challenge 5 (C5):select zygotes in tt x TT P sq | Challenge 6 (C6): select zygotes in Tt X Tt Punnett Square | Number of Attmpts per Challenge | Time per Challenge (min) | Multiple Choice Question (after Challenge 5):Offspring Outcome from the cross tt x TT | Multiple Choice Question (after Challenge 6): Offspring outcome from the cross Tt x Tt | No. of times seeking help (*type) | No. of times practice (type) \| time in min |
| Laurie | 22.10 | 27 | 0.82 | 1 | 0 | 0 | 1 | 2 | 0 | 1 | 0 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 1.2 | 1.35 | Y | Y | 0 | 0 |
| Matthew | 12.68 | 29 | 0.44 | 0 | 0 | 0 | 3 | 4 | 0 | 0 | 0 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.48 | N | Y | 0 | 0 |
| Eleanor/Nelly | 16.40 | 14 | 1.17 | 3 | 1 | 0 | 0 | 7 | 0 | 0 | 0 | 8 | 1 | nil | nil | nil | nil | nil | nil | 1.10 | nil | nil | 1[a] | 0 |
| Mark | 14.93 | 24 | 0.62 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1.3 | 1.13 | N | Y | 0 | 0 |
| Ada | 4.50 | 23 | 0.20 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.42 | Y | Y | 0 | 0 |
| Iris | 18.12 | 49 | 0.37 | 7 | 2 | 0 | 2 | 10 | 0 | 3 | 0 | 17 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.98 | Y | Y | 2[a]; 2[b] | 1[c] |
| Nora | 2.53 | 8 | 0.32 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | nil | nil | nil | nil | nil | nil | nil | nil | nil | nil | 0 | 0 |
| Maurice | 8.75 | 32 | 0.27 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 0 | 5 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 0.61 | N | N | 0 | 0 |

[a] Meiosis [b] Pedigree [c] Tails rule

Table A1.4.3

*Composite Data Table showing Participating Students' Learning Outcomes in School A*

| Participating students (pseudonyms) | Researcher's Online Tests(two-tier items only) (%) | | | | Teacher's tests (%) | | Assignments (%) | | Highest SOS [a] |
|---|---|---|---|---|---|---|---|---|---|
| | Pretest | Posttest | Pretest //items [b] | Posttest //items [b] | Test 1 | Test 2 | 1 | 2 | Level Awarded |
| Ada | 0.0 | 62.5 | abs | 66.7 | 61.2 | 52.8 | nil | 79.0 | 4 |
| Amanda | 36.4 | abs | 50.0 | abs | 43.1 | 43.5 | nil | 71.0 | 3 |
| Ann | 9.1 | 37.5 | 0.0 | 50.0 | 33.6 | 45.4 | nil | nil | 3 |
| Doug | 27.3 | 100.0 | 0.0 | 100.0 | 66.4 | 56.5 | nil | 79.0 | 6 |
| Eleanor | 18.2 | 25.0 | 0.0 | 33.3 | 45.7 | 40.7 | nil | nil | 3 |
| Eric | 18.2 | 50.0 | 16.7 | 50.0 | 43.1 | 38.9 | 51.7 | nil | 3 |
| Iris | 9.1 | 50.0 | 16.7 | 33.3 | 44.0 | 23.1 | 71.7 | 37.1 | 3 |
| Laurie | 36.4 | 37.5 | 33.3 | 33.3 | 63.8 | 45.4 | 73.3 | 83.9 | 5 |
| Lawrence | 18.2 | 37.5 | 0.0 | 33.3 | 44.0 | 35.2 | 70.0 | nil | 3 |
| Lillian | 0.0 | 62.5 | abs | 66.7 | 62.1 | 63.9 | nil | 80.6 | 6 |
| Louis | 9.1 | 50.0 | 0.0 | 66.7 | 37.1 | 41.7 | nil | nil | 3 |
| Luke | 45.5 | 75.0 | 16.7 | 83.3 | 83.6 | 80.6 | 78.3 | 82.3 | 6 |
| Mark | 9.1 | 75.0 | 16.7 | 83.3 | 55.2 | 57.4 | 60.0 | 53.2 | 4 |
| Matthew | 63.6 | 100.0 | 33.3 | 100.0 | 71.6 | 90.7 | 80.0 | 116.1 | 6 |
| Maurice | 0.0 | 62.5 | abs | 33.3 | 52.6 | 56.5 | 93.3 | nil | 3 |
| Neil | 18.2 | 75.0 | 0.0 | 83.3 | 52.6 | 62.0 | 50.0 | 88.7 | 3 |
| Nelly | 45.5 | 50.0 | 50.0 | 33.3 | 66.4 | 67.6 | 93.3 | 93.5 | 6 |
| Nelson | 45.5 | 50.0 | 33.3 | 50.0 | 50.0 | 67.6 | 68.3 | 85.5 | 3 |
| Nick | 0.0 | 50.0 | 0.0 | 50.0 | 55.2 | 51.9 | 60.0 | 64.5 | 3 |
| Nora | 27.3 | 50.0 | 0.0 | 66.7 | 62.1 | 66.7 | 81.7 | 75.8 | 3 |
| Norman | 18.2 | 50.0 | 0.0 | 50.0 | 48.3 | 41.7 | 73.3 | nil | 3 |
| Rita | 0.00 | 37.5 | 0.0 | 50.0 | 24.1 | 43.5 | nil* | 32.3 | 3 |
| Simon | 45.5 | 75.0 | 16.7 | 66.7 | 86.2 | 88.9 | 83.3 | 91.9 | 6 |
| Yvonne | 36.4 | 37.5 | 50.0 | 50.0 | 55.2 | 29.6 | nil | nil | 3 |
| Average | 25.6 ($n$ = 21) | 56.5 ($n$ = 23) | 14.2 ($n$ = 20) | 58.3 ($n$ = 20) | | | | | |

[a] Student Outcome Statements (see section 4.1.3.4)

[b] //items = parallel items

Table A1.5.1

*Chronology of Classroom Observation and Research Activities in School B*

| Date of Visit (2001) | Topic Taught in Observed Lessons | Other Activities/Remarks |
|---|---|---|
| 28 May (Mon) | | Meeting with Miss Bell's teacher supervisor Mr Nicholson to formalise participation |
| 5 June (Tue) | | Meeting the Principal but unable to see John or the IT teacher, collected some documents about School B |
| 6 June (Wed) | Introduction; variations | Classroom observation |
| 7 June (Thurs) | (Meiosis) | Not observed; collected Miss Bell's notes and overhead projection transparencies |
| 11 June (Mon) | | First Interview with Miss Bell |
| 12 June (Tues) | Polygenic inheritance—eye colour activity | Classroom observation |
| 13 June (Wed) | Mutations and genetic diseases | Classroom observation.<br>Both the researcher and Miss Bell were unable to contact IT teacher despite sending him several email messages; |
| 14 June (Thurs) | Online learning; online test did not work; *BioLogica* was not installed; students used the online virtual classroom and found discussion forum particularly interesting and exciting and interactive by posting 150+ articles in the lessons | Classroom observation.<br>Online test did not work for technical reasons; IT teacher had not installed *BioLogica* for Miss Bell; most of the 150+ articles they posted in 30 minutes were not about genetics |
| 15 June (Fri) | | No class; students visit TV station |
| 20 June (Wed) | Mutations; natural selection | Classroom observation; audio-/video-taped |
| 21 June (Thurs) | *BioLogica* activities: 'Introduction' and 'Meiosis' | Classroom observation; audio-/video-taped; researcher talked with some students as a participant-observer |
| 22 June (Fri) | (DNA and Forensic science) | Not observed; three students did the online posttest |
| 24 June (Tues) | | Second Interview with Miss Bell |
| 24 July (Tues) | | "Member-checking", reflections and follow-up discussion with Miss Bell |

Table A1.5.2

*Analysis of Miss Bell's Responses to the Genetics Online Tests*

| Content of the two-tier Items [a] | Online Responses : (√ = correct; x = incorrect ) | | | | | | | | Gene Conceptions /Genetics Reasoning Types |
|---|---|---|---|---|---|---|---|---|---|
| | Pretest sample 1[b] (2 June 2001) | | Pretest sample 2 (13 June 2001) | | Pretest sample 3 (14 June 2001) | | Posttest sample (27 June 2001) | | |
| | Tier 1 | Tier 2 | Tier 1 | Tier 2 | Tier 1 | Tier 2 | Tier 1 | Tier 2 | |
| 1.Are genes of all cells in humans same? | X | x | √ | √ | √ | √ | not in posttest | | Different cell types in the human body contain same genes. |
| 2.Three-generation pedigree problem | X | √ | √ | √ | X | √ | x | √ | Type IV genetics reasoning [c] |
| 3.Determine number of chromo-somes in gametes given number of chromosome pairs in zygote. | x | x | x | √ | x | x | √ | √ | Gametes receive one chromosome from each pair of chromosome s during meiosis; Type VI genetics reasoning |
| 4.Predict offspring phenotype in the cross: Bb x bb | √ | √ | x | x | √ | √ | not in posttest | | Type II genetics reasoning |
| 5."Black box" about meiosis [d] | not in sample | | √ | √ | x | x | √ | √ | Independent assortment of alleles in meiosis; Type VI genetics reasoning |
| 6.Ontology of a gene | x | x | x | x | x | x | x | x | A\gene as a set of productive sequence of instruction (process); type V genetics reasoning |

[a] The number in column one does not correspond to the item number in a particular test (see Appendix 2, Figures A2.4.1 to 2.4.6 for examples of each type of genetics reasoning).
[b] Paper and pencil version of the online pretest sample.
[c] See Table 3.1.
[d] See Appendix 2, Figure A2.4.6 for full text of the item.

Table A1.5.3

*Miss Bell's Gene Conception Before and After Teaching Genetics in School B*

| Online Tests (except pretest sample 1) | Gene Conceptions (Open-ended and 2-tier items in online tests) |
|---|---|
| Pretest sample 1 (a paper-and-pencil version ) (2 June 2001) | "It can be dominant or recessive" (open-ended question) The smallest unit of structure in a chromosome because it describes the chemical nature of a gene for a characteristic (two-tier item) |
| Pretest sample 2 (13 June 2001) | "It is a particle on a chromosome and its function is to control characteristic." (open-ended question) A segment of DNA molecule in a chromosome because it describes the chemical nature of a gene (two-tier item on type V reasoning). |
| Pretest sample 3 (14 June 2001) | It determines what trait an offspring will have (open-ended question). A segment of DNA molecule in a chromosome because it describe the structural relationship between a gene. |
| Posttest sample (27 June 2001) | Genes occur on chromosomes which hereditary characteristics (such as eye, hair, skin colour) are determined. An offspring receives hereditary material from both the mother and the father, therefore they are a mixture of both parents, this is why they can look like their mum or dad and they look similar to their siblings. When things go wrong, genetic diseases and mutations can arise. One tiny change can cause drastic effects. |

Table A1.6.1

*Chronology of Classroom Observations and other Research activities in School C*

*Part 1 (before Mid-term Break)*

| Date of visit (Cycle Day) | Topic in Observed Lessons/Tests | Other Activities/Remarks |
|---|---|---|
| 9 May 2002 | | Meeting the teachers: Ms Claire and Mrs Dawson |
| 13 May 2002 | | Interview with Ms Claire |
| 15 May 2002 | | Send web course login information to teachers; Interview with Mrs Dawson |
| 16 May 2002 | | Talk to IT person Ms Smith to seek advice for installation of *BioLogica* |
| 20 May 2002 | Ms Claire: Sexual and asexual reproduction Mrs Dawson's Class: same topic | Installation of *BioLogica* in class from my CD-ROMs |
| 21 May 2002 (D5) | Mrs Dawson: use online resources about reproduction and cell division | Preinstructional (Pre) interview with Elaine |
| 22 May 2002 | Ms Claire: chromosomes and mitosis<br>Mrs Dawson: mitosis | Pre interview with Rita |
| 23 May 2002 (D1) | Ms Claire: Human karyotype, Mitosis & Meiosis | Pre interview with Anne. |
| 24 May 2002 | Mrs Dawson: Meiosis; *BioLogica* meiosis activity<br>Ms Claire: Meiosis, comparison of mitosis & meiosis; *BioLogica* meiosis activity | Susan came to help; both classes used *BioLogica* meiosis activity; Pre interview with Cindy and Pre interview with Andrea. |
| 27 May 2002 | Mrs Dawson: comparison of mitosis & meiosis; *BioLogica* meiosis activity;<br>Ms Claire: Revision; view cell division animation; internet resources;*BioLogica* meiosis activity, Minitest | Pre interview with Etta; Pre interview with Terri. |
| 28 May 2002 | Ms Claire: Karyotype, homologous chromosomes, genes and alleles (basic genetics concepts); human genetics;<br>Mrs Dawson's Class: Karyotype, chromosomes, Minitest | Simulation game with colour square papers |
| 29 May 2002 (D5) | Mrs Dawson: human genetics; introduction to genetics concepts; pedigree | Simulation game with colour square papers; Pre interview with Isabelle; Erika did not turn up for the interview. |
| 30May 2002 | Core Test 1 | Pre interview with Erika. |
| | Mid-term Break (31 May-3 June) | |

Table A1.6.2

*Chronology of Classroom Observations and other Research activities in School C Part 2 (after Mid-term Break)*

| Date of visit (Cycle Day) | Topic in Observed Lessons/Tests | Other Activities/Remarks |
|---|---|---|
| 4 June 2002 | Ms Claire: discussion of core test results; more genetics terminology | |
| 5 June 2002 | Ms Claire: use dataprojector to demo BioLogcia monohybrid activity; students use *BioLogica* Monohybrid activity | |
| 6 June 2002 | Mrs Dawson:use dataprojector to demo *BioLogica* monohybrid activity; students use *BioLogica* Monohybrid activity;<br>Ms Claire: video show about genes and DNA; solving monohybrid problems with Punnett square | Susan (helper) came to observe Mrs Dawson's class; the Head of Department of Science visited Mrs Dawson's classroom |
| 11 June 2002 | Mrs Dawson: Monohybrid cross; assign group presentations based on "Your genes your health" website. | I missed the train for Ms Claire's class (She assigned topics for group presentation) |
| 12 June 2002 (Day 1) | Ms Claire: Group presentations on "Your genes your health" | |
| 13 June 2002 | Mrs Dawson: monohybrid cross continued; some group presentations<br>Ms Claire: more group presentatons | |
| 17 June 2002 (Day 4) | Ms Claire: Summing up p. 264, 265, Monohybrid activities; revision | |
| 19 June 2002 (Day 6) | Ms Claire: DNA double helix model; cut & paste<br>Mrs Dawson: Textbook problems, revision | |
| 20 June 2002 | Ms Claire: DNA replication; DNA workshop | |
| 21 June 2002 | Core test 2 | |
| 24 June 2002 | Mrs Dawson: DNA double helix model<br>Ms Claire: laptop computer upgrade; some revision | |
| 25 June 2002 | Ms Claire: DNA extraction<br>Mrs Dawson: DNA extraction /test for campers | |
| 26 June 2002 | Mrs Dawson: DNA model; DNA fingerprinting | |
| 27 June 2002 | Ms Claire: Posttest; molecular detectives/DNA fingerprinting<br>Mrs Dawson: Posttest; | Postinstructional (Post) interview (Rita);<br>Post interview (Elaine); |
| 28 June 2002 (Day 1) | Ms Claire: Discuss DNA worksheet/Molecular detectives/DNA fingerprinting; protein synthesis | Post interview (Andrea & Nancy); Post interview (Isabelle & Eva); |
| 1 July 2002 | Mrs Dawson: DNA and protein synthesis<br>Ms Claire: DNA protein synthesis ( in much detail); use website DNA workshop | Post interview (Cindy & Amelia); Homework reading GE handout |
| 2 July 2002 | Mrs Dawson: upgrading of laptop computers<br>Ms Claire: genetic engineering/video with worksheet | Post interview (Anne & Naomi); 3rd interview with Andrea. |
| 3 July 2002 | Ms Claire: Discuss questions in the worksheet on *Genetic Engineering* | Post interview (Terri & Anna); Feedback on pretest-posttest comparison |
| 4 July | Mrs Dawson's Class discussion of worksheet on genetic engineering and related ethical issues. | 2nd Post interview (Terri, Irene, and Andrina); Post teacher interviews. |
| 5 July | Core Test 3 | DNA and genetic engineering |

Table A 1.7.1

*Chronology of Classroom Observation and Research Activities in School D: Part 1*

| Date of visit<br>Date (Day) | Topic in Observed Lessons/Tests<br>(Y12 Bio/H Bio = Year 12 Biology/Human Biology Class) | Other Activities/Remarks |
|---|---|---|
| 1 July 2002 | | Meeting Ms Elliott |
| 19 July 2002 | | Planning for the project with Ms Elliott; formalisation of participation |
| 22 July 2002 (Mon) | Y12 Bio: Introduction to *BioLogica* research and try out login information; video show "Evolution for understanding; some teaching on evolution, e.g., divergent and convergent evolution | Interview with Ms Elliott; met the Principal |
| 23 July 2002 (Tues) | | Worked with the IT person to install *BioLogica* |
| 24 July 2002 (Wed) | Y12 Bio: Pretest and *Meiosis* (one student was absent); handout for HW. | |
| 25 July 2002 (Thu) | Y12 Bio: HW discussion (D01); discuss monohybrid cross by referring to *BioLogica*; Punnett square; *Monohybrid* | Karl got 100% in his Pretest! *Monohybrid* not complete |
| 26 July 2002 (Fri) | Y12 Bio: Monohybrid cross; inheritance pattern (a tree-like taxonomy); workbook; introduction to dihybrid cross; repeated *Monohybrid* | Only Margaret did *Horn Dilemma* |
| 29 July 2002 (Mon) | Y12 Bio: Dihybrid cross; pedigree chart icons etc (cf BL); *Dihybrid*<br>Y12 H Bio: Introduction to *BioLogica*; Pretest; *Introduction* | Students did not understand the expected F2 from ppRR x PPrr |
| 30 July 2002 (Tue) | Y12 H Bio: Repeated *Introduction*, *Rules* | Ms Elliott was absent |
| 31 July 2002 (Wed) | Y12 Bio: Discussion textbook questions; handout on sex-linked inheritance (D02); repeat inheritance pattern taxonomy by referring to *BioLogica*; *Sex Linkage*<br>Y12 H Bio: briefed class to jot down notes while using *BioLogica*; questions on white board; *Rules* | Y12 Bio *Sex Linkage* incomplete;<br>Only six students were present in Y12 H Bio class |
| 1 Aug 2002 (Thu) | Y12 Bio: Redo *Sex Linkage*; more about recognition of inheritance pattern | Y12 Bio students found Hamster investigation interesting. |
| 2 Aug 2002 (Frid) | Y12 Bio: co-teaching to give feedback to students on *Sex Linkage*; pedigree analysis on workbook and more on inheritance pattern; *Inheritance* and *Rules*<br>Y12 H Bio: HW discussion; dominant/recessive and homozygous /heterozygous in relation to meiosis; *Inheritance* | Only 10 students in Y12 H Bio class; only the first part of *Meiosis* was done |
| 5 Aug 2002 (Mon) | Y12 Bio: HW discussion (workbook problems n pedigree analysis p. 301-302); *Mutations*<br>Y12 H Bio: HW discussion textbook p. 16; briefed class and they do the third part of *Meiosis* (*Design Dragons*) | As Ms Elliott e-mailed me that she had problems using *Meiosis*, I helped her before the lesson); Susan was in to observe the classes: lesson recorded (3 tapes each class) |
| 6 Aug 2002 (Tue) | Y12 H Bio: HW discussion; about tongue-rolling and then a review; briefed about *Monohybrid*; handout "Inheritance by genes" (D01); *Monohybrid* | Phoebe did not know the controlled alignment function and I showed her how to use it (see log files) |

**BioLogica* activities are given in upper case, e.g., *Meiosis*

Table A1.7.2

*Chronology of Classroom Observation and Research Activities in School D: Part 2*

| Date of Visit Date (Day) | Topic in Observed Lessons/Tests | Other Activities/Remarks |
|---|---|---|
| 7 Aug 2002 (Wed) | Y12 Bio: Assessment (not observed; but scripts copied)<br>Y12 H. Bio: | |
| 8 Aug 2002 (Thu) | Y12 Bio: *Pedigree analysis* (2-page TEE multiple choice questions), *pattern recognition, twins* and *test cross* | Appointments with students for the interviews; discussed with Ms Elliott for *Scales* on Fri |
| 9 Aug 2002 (Fri) | Y12 Bio: Briefed the class through some co-teaching and then *Scales*; some co-teaching before the after the activity<br>Y12 H Bio (not observed) | Y12 Bio class given a dragon genome sheet; Absent from Y12 H Bio for attending Peter Hewson's talk; Helena did the *Scales*! |
| 12 Aug 2002 | HOLIDAY | |
| 13 Aug 2002 (Tue) | Y12 H Bio: *Sex Linkage* ; Ms gave individual feedback to the Phoebe and some other students using the logs with my comments | Recording dialogues/Helena and May during the computer session; their log files available |
| 14 Aug 2002 (Wed) | Y12 Bio: Talked about newspaper feature "Groom's Intersex (XXY) Quandary"; Posttest<br>Y12 H Bio: Talked about newspaper feature " Groom's Intersex (XXY) Quandary"; review of what was covered: 1. sex determination, 2.pedigree construction, and 3. inheritance patterns (autosomal& sex-linked) using examples from a handout* | Students got immediate feedback from WebCT and from Ms Elliott (Mark got 100%!); |
| 16 Aug 2002 (Thu) | Y12 Bio: co-teaching feedback on posttest questions students given their scripts (Posttest Q20/21); evolution: variation, mutations and natural selection; more feedback on the blackbox problem (Posttest Q12/13)<br>Y12 H Bio: discussion of the previous day's handout continued; assignment test; log files feedback to Helena, May, Paul, Alina, Audrey | |
| 19 Aug 2002 (Mon) | Y12 H Bio: some teaching on mutation e.g., skin colour protects us from UV etc. and DNA as instruction for proteins; co-teaching to brief the class with a handout with program snapshots; *Mutations*; my scaffolding to kids | Interview of Y12 Bio students;<br><br>Dialogue between Helena and May tape-recorded. |
| 20 Aug 2002 (Tue) | Y12 H Bio: discussion of assignment test done on 16 Aug; pattern recognition in pedigree analysis; natural selection; coteaching to give feedback to students | Print-outs as individual feedback on *Mutations* |
| 21 Aug 2002 (Wed) | Y12 H Bio (not observed) | Interview of Y12 Bio students |
| 23 Aug 2002 (Fri) | Y12 H Bio: Evidence to support evolution | Appointments to interview Y12 Human Bio students |
| 26 Aug 2002 (Mon) | Y12 H Bio: Posttest; besides the feedback provided b WebCT , Ms Elliott immediately gave more feedback to the students using the hard copy of the test I gave her. | Only 6 did the Posttest; five Y12 Human Bio students away for work experience the whol week. |
| 27-30 Aug | | Y12 H Bio Interviews |
| 2-4 Sep | | More Y12 H Bio Interviews |
| 13 Sep | | Post Interview with Ms Elliott |

*Genetics-terminology and frequency predictions

Table A1.7.3

*Summary of Log Files of Year 12 Human Biology Class in School D*

| Students | *BioLogica* Activities | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Introduction* | *Rules* | *Meiosis* | *Inheritance* | *Monohybrid* | *Mutations* | *Sex Linkage* | Individual Total |
| Alina | 2 | 1 | 1 | 4 | 1 | 1 | 3 | 13 |
| Audrey | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 9 |
| Edith | 0 | 2 | 2 | 1 | 0 | 2 | 2 | 9 |
| Elisa | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 10 |
| Ella | 3 | 1 | 1 | 1 | 1 | 2 | 0 | 11 |
| Helena | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| Hilda | 1 | 3 | 3 | 1 | 1 | 1 | 2 | 13 |
| Kath | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 10 |
| May | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 8 |
| Paul | 2 | 2 | 2 | 3 | 2 | 1 | 1 | 13 |
| Phoebe | 2 | 3 | 5 | 2 | 3 | 2 | 1 | 18 |
| Activity Total | 18 | 19 | 20 | 19 | 13 | 14 | 16 | 119 |

Table A1.7.4

*Summary of Log Files of Year 12 Biology Class in School D*

| Students | *BioLogica* Activities | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Rules* | *Meiosis* | *Inheritance* | *Monohybrid* | *Mutations* | *Mutation Inheritance* | *Dihybrid* | *Sex Linkage* | *Scales* | Individual Total |
| Bob | 1 | 3 | 0 | 3 | 2 | 2 | 1 | 2 | 1 | 15 |
| Hilary | 1 | 2 | 1 | 2 | 1 | 0 | 1 | 3 | 1 | 12 |
| John | 1 | 2 | 1 | 2 | 1 | 0 | 1 | 1 | 1 | 10 |
| Juvena | 1 | 3 | 1 | 3 | 1 | 0 | 1 | 1 | 1 | 12 |
| Karl | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 10 |
| Margaret | 1 | 1 | 2 | 3 | 1 | 0 | 2 | 2 | 0 | 13 |
| Activity total | 6 | 11 | 6 | 14 | 7 | 3 | 8 | 11 | 5 | 71 |

Table A1.7.5

*Comparison of Year 12 Student Learning Outcomes in School D*

| Class | Name | Online Pretest | Online Posttest | Assignment* | Practical (Huntington Lab) | Teacher's Tests* |
|---|---|---|---|---|---|---|
| Human Biology Class | Alina | 30.8 | 30.8 | 26 | 65 | 78 |
| | May | abs | 50.0 | 40 | 40 | 76 |
| | Phoebe | 69.2 | 84.6 | 82 | 80 | 71 |
| | Ella | 53.8 | 53.8 | 42 | 40 | 41 |
| | Edith | 53.8 | abs | 82 | 45 | 57 |
| | Paul | 23.1 | 61.5 | 76 | 75 | 73 |
| | Audrey | 15.4 | 61.5 | 36 | 85 | 63 |
| | Kath | 23.1 | 38.5 | 62 | 30 | 56 |
| | Elisa | 30.8 | 76.9 | 84 | 60 | 78 |
| | Helena | 15.4 | 46.2 | 36 | abs | 56 |
| | Hilda | 23.1 | abs | 34 | abs | abs |
| Biology Class | Karl | 100 | 100 | 97 | 80 | 84 |
| | Bob | 76.9 | 84.6 | 81 | 40 | 85 |
| | Margaret | 46.2 | 69.2 | 89 | 85 | 74 |
| | Hilary | 53.8 | 61.5 | 83 | abs | 64 |
| | Juvena | 53.8 | 46.2 | 56 | 60 | 61 |
| | John | 38.5 | 38.5 | 58 | 60 | 56 |

*Both the assignments and the teacher's test in the two classes are different

# Appendix 2: Figures

## —Website, Online Test Items and Students' Work

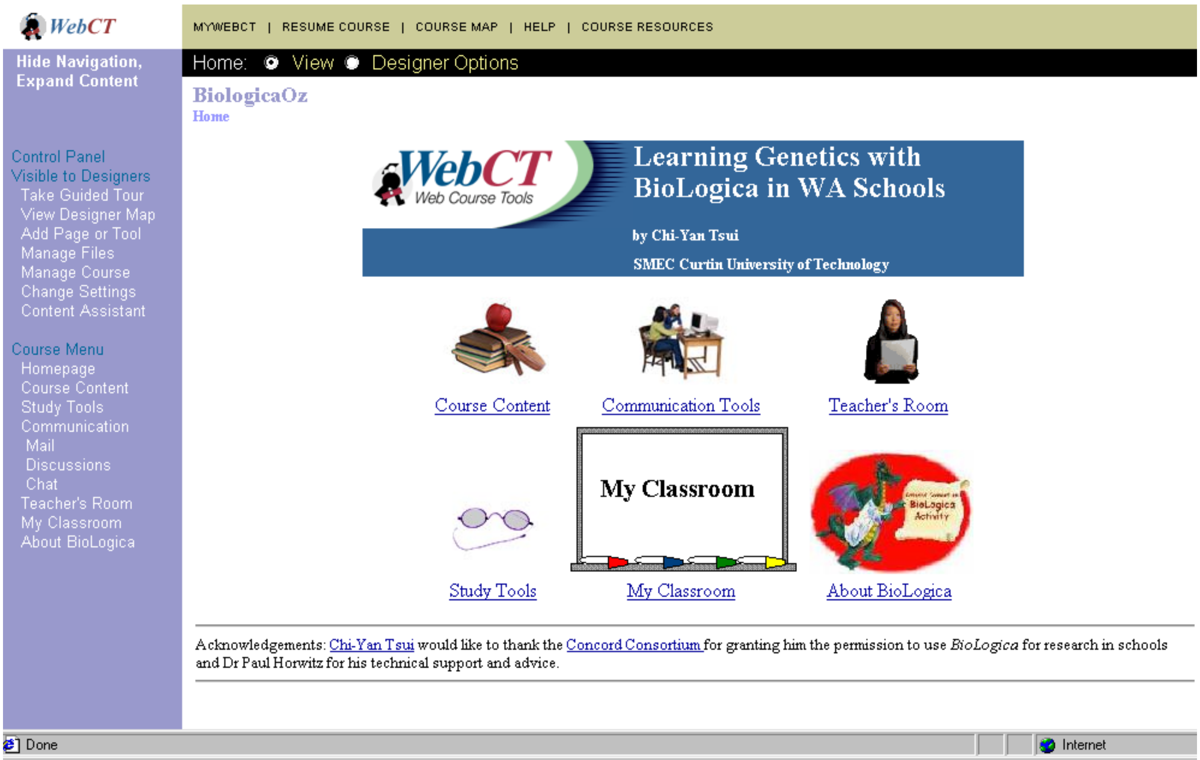



*Figure A2.1.1* Screenshot of homepage of the website during the study in School A (April 2001). (URL: http://webct.curtin.edu.au/public/BiolOz_a/index.html )

**Question 2 (1 point)**

The trait, curly hair, is dominant to straight hair. If we use "C" to represent the dominant allele (gene) for curly hair and "c" for the recessive allele, would a person with genotype Cc have curly hair?

- a. Yes
- b. No
- c. Don't know

**Question 3 (1 point)**

Reason for Question 2:

- a. The person needs to have CC for curly hair.
- b. The dominant allele C is expressed in a Cc condition.
- c. The person may or may not have curly hair.
- d. The recessive allele c is expressed.

---

*Figure A2.4.1* A sample of a two-tier item on Type I genetics reasoning.

**Question 6 (1 point)**

In mice, the gene allele b for white skin is recessive to B for brown skin. A male mouse with genotype Bb was mated to a female mouse with the genotype bb and then gave birth to a litter of 12 mice. How many mice in the litter are expected to be white?

- a. 3
- b. 6
- c. 12
- d. Don't know

**Question 7 (1 point)**

Reason for Question 6:

- a. Half of the sperms but all the eggs carry the b allele.
- b. All the sperms but half of the eggs carry the b allele.
- c. There is only one possible fertilisation event.

*Figure A2.4.2* A sample of a two-tier item on Type II genetics reasoning.

**Question 24 (1 point)**

Peter is an albino who was born without the ability to make a pigment in the skin. Albinism is a recessive characteristic. Suppose we use "A" for the dominant gene (allele) and "a" for the recessive gene, what would be Peter's genotypes (genes) for albinism?

a. AA or Aa

b. Aa or aa

c. aa

d. Don't know

**Question 25 (1 point)**

Reason for Question 24:

a. Because Peter must have at least one recessive allele "a".

b. Because one recessive allele "a" does not make Peter an albino.

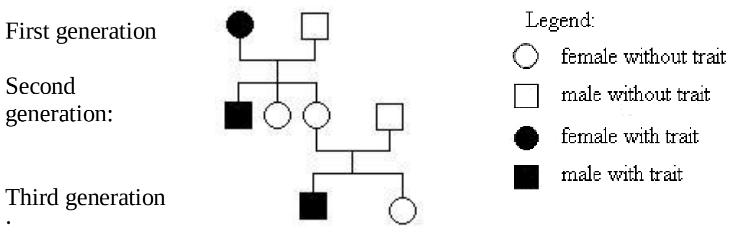
c. Because recessive allele "a" is only expressed in Peter when present in "Aa" form

---

*Figure A2.4.3* A sample of a two-tier item on Type III genetics reasoning.

FIRST TIER:

Which of the following best describes the trait (characteristic or feature) in the given pedigree (family tree)?




I. Recessive II Dominant III Cannot tell IV Don't know

SECOND TIER:

Reason:

A.Only one of the three children in the second generation has the trait (characteristic or feature).
B.Both the female in the first generation and her son have the trait (characteristic or feature)
C.One male in third generation has the trait (characteristic or feature) but his parents do not have it.
D.The trait (characteristic or feature) can be either recessive or dominant.

*Figure A2.4.4* A sample of a two-tier item on Type IV genetics reasoning.

### Question 18 (1 point)

Which one of the following is the best description of a gene?

- a. The smallest unit of structure in a chromosome.
- b. A sequence of instructions that codes for a protein.
- c. A segment in a DNA molecule.
- d. Don't know.

### Question 19 (1 point)

Reason for Question 18:

- a. It is about the information of a gene for producing a characteristic.
- b. It is about the structural relationship between a gene and a chromosome.
- c. It is about the chemical nature of a gene.
- d. It is about the gene being a protein.

---

*Figure A2.4.5* A sample of a two-tier item on Type V genetics reasoning.

**Question 14 (1 point)**

The following shows a “black box” that provides a simplified model to show a process in genetics:

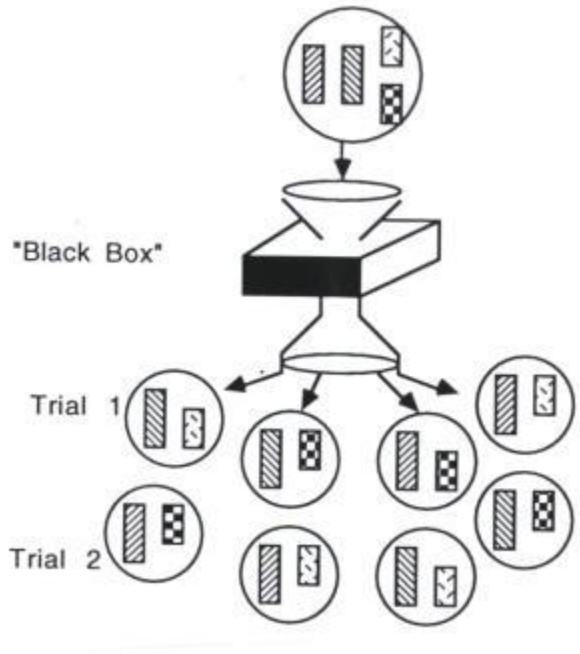



Diagram adapted from Kinnear, J.(1992, March). *Teaching genetics: Recommendations and research*. Paper presented at the Teaching Genetics: Recommendations and Research Proceedings of a National Conference, Cambridge, Massachusetts.

What does the “black box” represent?

- a. Fertilisation process in which a sperm combines with an egg.
- b. A kind of cell division that takes place after fertilisation.
- c. A kind of cell division that produces sperms or eggs before fertilisation.
- d. Don’t know.

**Question 15 (1 point)**

- a. The chromosomes combine in pairs to form different cells in the body.
- b. The cell divides into different cell types with different chromosomes for different functions in the body.
- c. The cell divides into daughter cells that have half the number of chromosomes.
- d. The results are similar in the two trials.

*Figure* A2.4.6 A sample of a two-tier item on Type VI genetics reasoning.

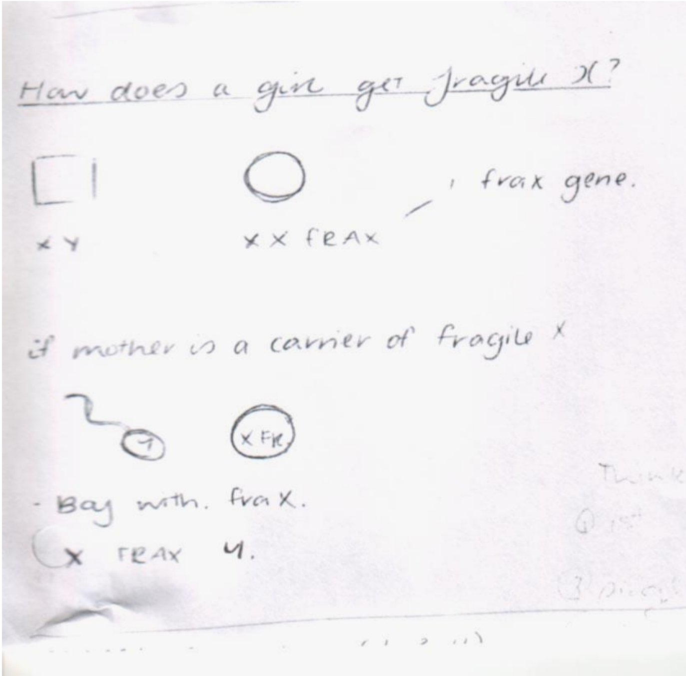
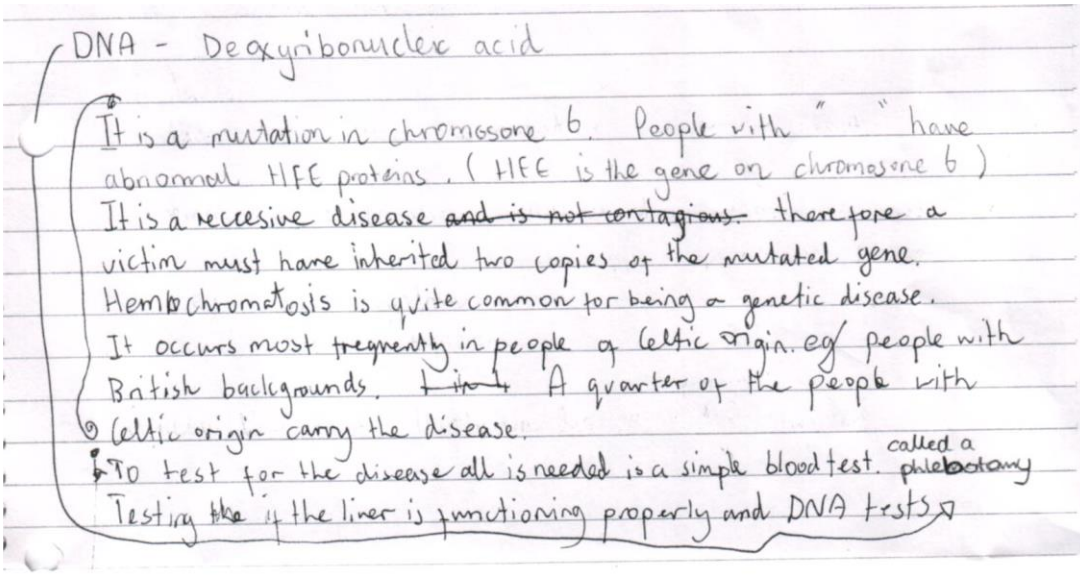



*Figure A2.6.1* Erika's visual-graphical representation of the inheritance of the Fragile X Syndrome (School C/Ms Claire's class).


DNA - Deoxyribonucleic acid

It is a mutation in chromosome 6. People with " " have abnormal HFE proteins. (HFE is the gene on chromosome 6) It is a recessive disease ~~and is not contagious.~~ therefore a victim must have inherited two copies of the mutated gene. Hemochromatosis is quite common for being a genetic disease. It occurs most frequently in people of Celtic origin. eg people with British backgrounds. A quarter of the people with Celtic origin carry the disease. To test for the disease all is needed is a simple blood test called a phlebotomy. Testing if the liver is functioning properly and DNA tests.

*Figure A2.6.2* Amelia's verbal-textual representation of the haemochromatosis gene on chromosome 6 (School C/Ms Claire's class).

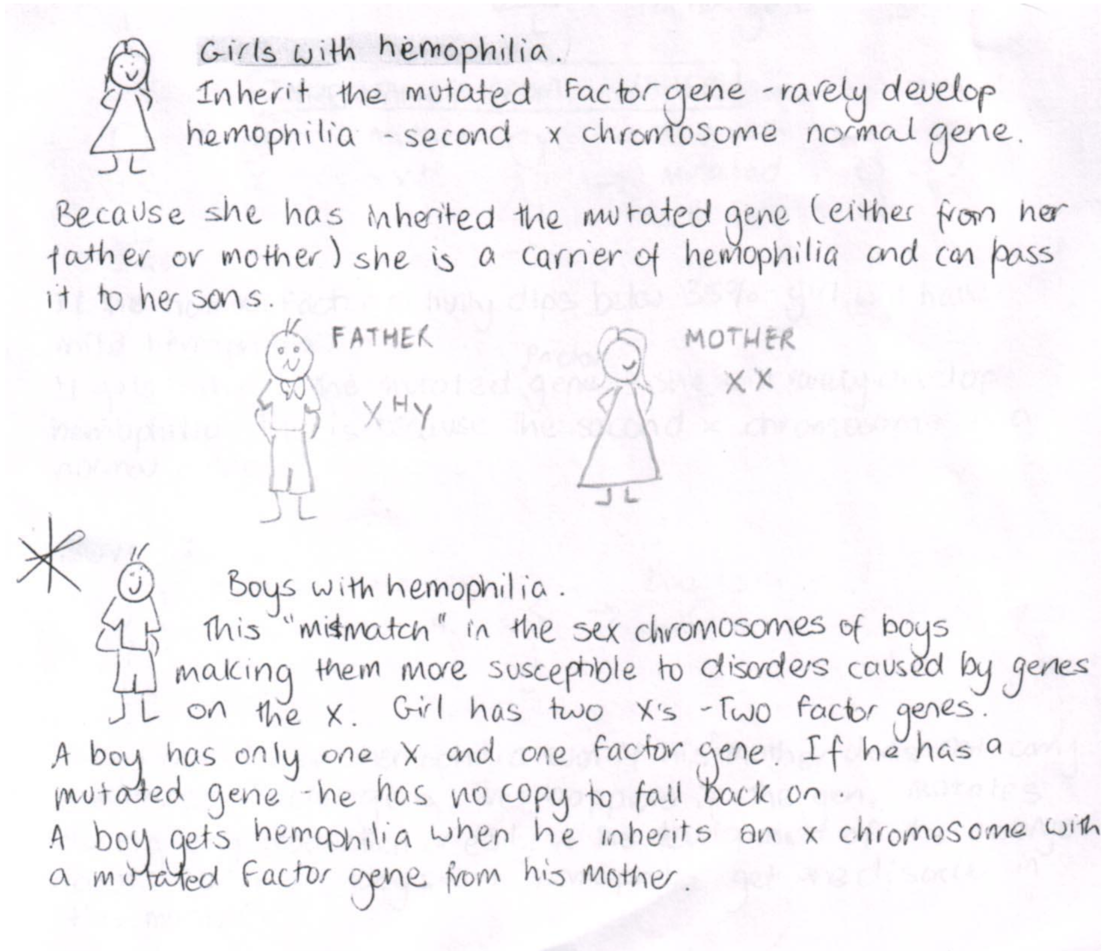



*Figure A2.6.3* Isabelle's multiple representations of the inheritance of haemophilia using annotated drawings (School C/Ms Claire's class).

# Appendix 3: Documents

## —Letters, Teaching Schemes, Interview Protocols and Log Files

*Document A3.1* Permission Letter for Using Material from the Australian Science Education Project (ASEP) Handbook Series.

---

**Department of**
**Education, Employment and Training**

Office of Schools

2 Treasury Place
East Melbourne, Victoria 3002
Australia

GPO Box 4367
Melbourne, Victoria 3001
Australia

Telephone +61 3 9637 2000
DX 210083

-6 APR 2001

SCHO39621

Chi-Yan Tsui
Course Tutor
Science and Mathematics Education Centre
Curtin University of Technology
GPO Box U1987
PERTH WA 6845

Dear Chi-Yan Tsui

Thank you for your letter to the Director of Schools dated 2 March, 2001 requesting the use of material from the Australia Science Education Project (ASEP) Handbook Series. I have been asked to respond on behalf of the Director.

The ASEP curriculum materials were widely used in the 1970s and some activities are still used today. The Department of Education, Employment and Training (DEET) grants you permission to use material from this publication for your doctoral studies providing DEET is appropriately acknowledged. Advice from our solicitor with responsibility for copyright, is that, acknowledgement of the State of Victoria, Department of Education, Employment and Training is sufficient.

I wish you well with your studies.

Yours sincerely

**Glenda Strong**
Acting General Manager
School Programs and Student Welfare Division

Victoria
The Place To Be

*Document A3.2* A Sample Letter to the Principal of School A (Mr Johnson is a pseudonym)

---

27 April 2001

The Principal,
School A,
Perth, Western Australia.

RE: Request for permission to enter the school to do research

Dear Mr Johnson,

I am a full-time doctoral student and a part-time course tutor at the Science and Mathematics Education Centre in Curtin University of Technology working with Professor David Treagust. I have recently been in contact with Mr Anderson, a science teacher of your school, who has agreed to take part in my research project for my doctoral thesis during Term 2. One other teacher is also interested in taking part in a similar study in Term 3.

My research project is to investigate secondary students' reasoning in genetics, a difficult but important topic in science and biology. One main objective is find out how teaching and learning of this topic can be improved. The teachers will teach as usual but they will integrate into classroom teaching and learning some computer-based activities using a very new interactive multimedia program and also some online learning. I will be in the classroom to observe and to offer some technical assistance to the teacher and the students when they use the computer activities but I will not interfere with the normal progress of teaching and learning. The students' computer log files will be analysed. A research helper from Curtin University will also be present in the classroom on some days to record the classroom observations. Some lessons will be audio-taped and/or video-taped for subsequent analysis.

Part of the data collection will involve individual interviews with the participating teachers and several participating students from Year 10 and Year 12 classes. The student interviews will be conducted twice. Each interview will take about 20 minutes and will be conducted at recess, lunch time or during any free lessons so that the students will not miss any important teaching time. Student participation in the interviews will be voluntary and any student's wish not to be involved will be respected. The data collected from the classroom, teachers and students, will be kept confidential. Pseudonyms will be used for all participants to preserve their anonymity in my thesis, conference presentations and journal publications. A letter will be sent to the students' parents/guardians through their teacher to inform them about the research and seek their consent for allowing their children to participate in interviews.

The purpose of this letter is to request your permission for me to enter your school to do this research. I hope you will support my project in your school. If you have any concerns about my request, please contact me on 92663791 (email tsuich@ses.curtin.edu.au ) or Professor David Treagust on 92667924 (email D.Treagust@smec.curtin.edu.au ).

I look forward to your reply.

Yours sincerely,

Chi-Yan Tsui

Document A3.3 Permission Letter from Dr Paul Horwitz (Concord Consortium, USA)

---


The Concord Consortium
Educational Technology Lab
37 Thoreau Street
Concord, MA
01742

978.369.4367
fax 978.371.0696
info@concord.org
www.concord.org


May 8, 2001

Mr Chi-Yan Tsui
Science & Mathematics Education Centre (SMEC)
Curtin University of Technology
Kent Street, Bentley,
Perth, WA 6102
Australia

Dear Mr Tsui,
As you know, I am the Principal Investigator on a project sponsored by the U.S. National Science Foundation, that is developing a piece of software called BioLogica™ intended for teaching genetics. BioLogica makes use of multiple, linked representations of objects such as organisms, genes, chromosomes, and DNA, and enables students to manipulate them and watch the effects. Inasmuch as your research project clearly parallels ours, I am pleased to confirm hereby that the Concord Consortium grants you permission to use the BioLogica software for your research. I understand that you will introduce BioLogica into various schools and other educational institutions in Western Australia in the course of your research for your PhD thesis, and I am happy to be able to support that work.
I would be pleased to provide you with technical advice if you need any. Please do not hesitate to contact me or my colleagues with any comments or suggestions that you may have.

Yours truly

Dr Paul Horwitz

*Document A3.4.1* Teaching Scheme of School A

**BIOLOGICAL CHANGE 6.2** **UNIT OBJECTIVES**

**UNIT DESCRIPTION**

This unit looks at organism characteristics, how these are inherited, and the effects man can have on their inheritance. It covers the consequences of mutations, genetic diseases and the processes of reproduction in both plants and animals. Biological Change 6.2 is the only biological unit at stage 6 and is a pre-requisite to the study of Biology and Human Biology at a Year 11 level.

**UNIT OBJECTIVES**

* explain the processes of reproduction (sexual and asexual) and how these help in passing on genetic information and characteristics from generation to generation
* explain the ways in which genetic information is stored and transmitted from cell to cell and generation to generation, and how recent technological advances have allowed humans to influence these processes
* explain how in sexually reproducing organisms different combinations of genetic material from each parent, and varying environmental conditions, produce a diversity of offspring and that the expected characteristics of oddspring can be predicted
* explain the major principles of population genetics giving examples of how inherited characteristics of populations can change over time
* demonstrate competence in experimental design, equipment manipulation, data collection and analysis
* discuss social issues relating to an improved knowledge of genetics and its associated technology

**SPECIFIC OBJECTIVES**

By the end of this unit you should be able to:

**REPRODUCTION**

1 Explain why it is important for organisms to reproduce.
2 Outline the differences between sexual and asexual reproduction.
3 Describe the parts and functions of the human reproductive system.
4 Explain what gametes are and what their function is in sexual reproduction.
5 Describe the development of the human embryo.
6 Describe the structure and function of fruits on plants and their importance.
7 Describe some examples of structural adaptions in plants and animals that help with fertilisation.
8 Describe some examples of structural adaptations in plants that help dispersion.

**CELL STRUCTURE AND FUNCTION**

9 Describe the structure of a cell and how it is the basic building block of all living things.
10 Explain what the nucleus of a cell is and describe its function.
11 Describe the nature of a gene.
12 Explain how growth involves an increase in cell size and also number by mitosis.
13 Outline the processes of mitosis (for growth) and meiosis(for gamete production) and explain the differences in their products and why these differences are necessary.
14 Explain that in the production of gametes and in fertilization, genes are passed on by chance and that probability can be predicted.
15 Outline some of the advances in technology that led to the discovery of chromosomes, genes and DNA.

**GENETICS**

16 Explain how reproducing sexually produces greater genetic variation.
17 Explain how the characteristics of an organism are determined by a combination

of genetic make up and environmental influence.

18 Explain how sex is inherited in humans.

19 Explain the importance of the work of Gregor Mendal to genetics.

20 Outline some of the advances in technology that led to the discovery of chromosomes genes and DNA.

21 Understand the terms hybrid (heterozygous) and pure (homozygous) strain.

22 Solve problems of inheritence based on monohybrid crosses.

23 Describe how sex linked genes ( eg. haemophilia, colourblindness) are passed on and effect humans.

24 Describe dominant, recessive, co-dominant and completely dominant examples of human characteristics.

## GENETIC MANIPULATION

25 Explain what a gene pool is using a characteristic such as blood group as an example.

26 List some major causes of mutations and explain why mutation is important as a source of variation in a gene pool.

27 Describe how natural selection can change the frequency of features or genes in a population or gene pool.

28 Describe some ways in which humans manipulate gene pools and explain the effects of these.

29 Describe ways in which genetics is used in animal husbandry, agriculture and medicine.

30 Explain what is meant by gene splicing.

31 Understand the applications of cloning.

32 Explain the uses of artificial insemination.

33 Understand the process of in vitro fertilization.

34 Be aware of reasons for genetic counselling.

35 Understand the need for detection of genetic diseases.

## VOCABULARY LIST

By the end of this unit you should know the meanings and spellings of these words:

| | | | | |
|---|---|---|---|---|
| reproduction | asexual | sexual | gamete | embryo |
| ovary | seed | cell | mitosis | meiosis |
| gene | hybrid | heterozygous | homozygous | pure-strain |
| dominant | recessive | co-dominant | blending | sex-linked |
| gene pool | chromosome | haploid | diploid | heredity |
| natural selection | mutation | competition | fission | chromatid |
| centromere | genotype | phenotype | allele | mutagen |
| Deoxyribonucleic acid | | genetic engineering | | |

## ASSESSMENT

The objectives for this unit will be assessed as follows:

| | |
|---|---|
| TEST 1 | 30 |
| TEST 2 | 30 |
| LIBRARY ASSIGNMENT | 10 |
| ASSIGNMENT 1 | 10 |
| ASSIGNMENT 2 | 10 |
| TEACHER MARK | 10 |

*Document A3.4.2* Mr Anderson's Problem about *Moronville* Customised for his Year 10 Class 2001 in School A. (Real names of students were replaced by pseudonyms.)

## CONSTRUCTING A PEDIGREE FOR A BUNCH OF MORONS

In an outback town called Moronsville, the community can he divided into two groups, those that pick their noses and those that do not. Nosepicking is inherited on a simple Mendelian basis. Nosepicking is recessive to non-nosepicking. Luke Jerk married Rita Dredgebucket and had 5 children: Ann, Emma, Peter, Isabelle and Erin. Jennifer and Erin are rampant nosepickers, no one else in the family indulges in a mucous meal. Emma Jerk grew up and married nosepicking Neil. Neil was the first born son of Nora and Norman Treaclebrains. He was followed by brother Alex. Norman and son Neil are the only members of the family who pick their noses. Alex Treaclebrains meets Natasa Leedhimastray and they marry and have 4 children named Eric, Simon, Matthew and Eleanor. Eleanor is the only one of the 4 children who does not pick her nose all day long! Emma and Neil Jerk had two children - nosepicking Amanda and non-nosepicking Nelson. Amanda meets Mark Braindead and raises 6 bouncing babies: Iris, Laurie, Lillian, Nelly and Doug. Laurie and Doug are the only ones who pick their noses. One of them is very good at digging them out! Lillian Braindead falls in love with Maurice Amistillhere. They eventually marry but Maurice doesn't like TV and can't afford the electricity and they raise 7 children: Yvonne, Lawrence, Mary, Ada, Sam, Matthew and Nick. Mark, Lawrence and Ada have a finger up their nose continuously. Sam, Matthew and Mary are clean living people from way back and do not pick their noses.

Construct a pedigree of this family of nosepickers as described. When you have finished answer the following questions.

1. How many people are there in the pedigree? _____________
2. How many male nosepickers are there? __________
3. Is the relationship between

   Lawrence and Erin? ___________
   Amanda and Laurie? ___________
   Lillian and Nelly ? __________

4. What are the genotypes of the following

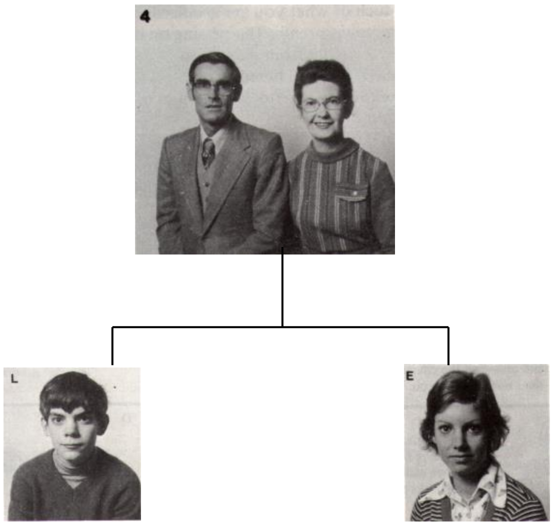
   Nora ___________ Simon ______________
   Laurie ________ Norman _____________
   Sam ___________ Mary _______________

5 If Alex and Laurie had children, what is the probability of them having a
   Boy? _______
   Nosepicker? _________
   Non-nosepicker? _________
   Nosepicking girl? __________

*Document A3.4.3* An Example of Student Interview Protocol. (*Photographs were used with Permission from the State of Victoria; see Document* A3.1)

***Pre-instructional Interview***

Part 1: (Pictures of parents and two children on a A4 sheet)



Pierre Marianne

1A.Why do Pierre and Marianne look like their parents ? (Probe genes)

1B. How would you best describe a gene ? Can you draw a picture of a gene and explain it to me?

1C. What is the relation between a gene and DNA ?

1D. What is the relations between DNA and chromosomes?

1E Explain to me how the genes get passed from parents to Pierre or Marianne? (Probe egg, sperms, fertilisation etc.)

1F. What do you a think a gene does ? (Probe "control characteristics") How does it do this ? etc.

Part 2: (Reasoning types: I (2A), III (2B), IV(2C), II, V & VI (2D) expected in their explanations; skip this part if the student knows nothing and does not wish to continue)

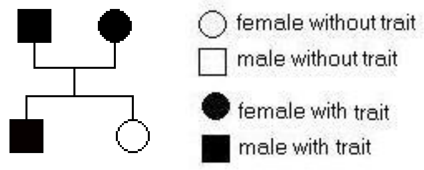
Given tongue-rolling is a dominant trait controlled by a dominant gene R and a recessive gene r, (If necessary, ask "do you know the meaning? If not, I will explain it to you").

2A: Suppose a girl has genotypes (genes) Rr, will she be able to roll the tongue. Explain your answers (the student can use paper and pencil to write or draw)…

2B: (Referring to the pedigree chart given) Marianne is the only one who cannot roll the tongue in the family. Do you know her genes? (Probe rr). Explain…(the student can use paper and pencil to write or draw)

(Show the following pedigree diagram on a A4 sheet to the student.).

Parents:




Pierre Marianne

2C: Do you know their parents' genes? Explain… (the student can use paper and pencil to write or draw while explaining)

2D: How about Pierre's genes for tongue-rolling ability? Explain (the student can use paper and pencil to write or draw while explaining)

Part 3:

Do you like science lessons? What do you like? Why ?….

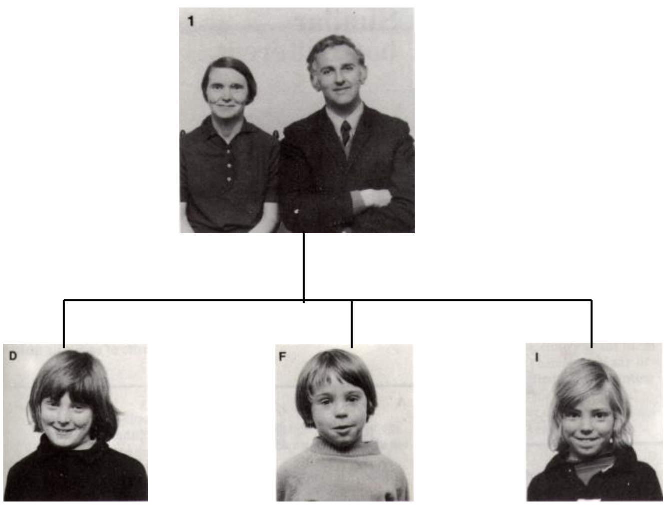
How do you like learning genetics? ……

Do you think the computer can help your learning?….

***Post-instructional Interview (Parallel form)***

Part 1: (Picture of a family with three children provided on an A4 sheet )

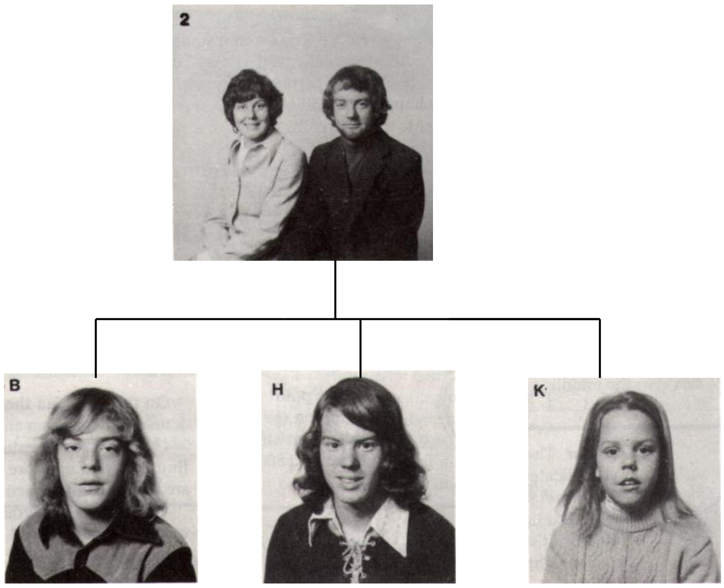
School A Version:



Dianne Flora Irena

Part 1: (Picture of a family with three children on an A4 sheet)

School C Version:




Patrick Jenny Kate

1A. Why do three children look like their parents ? Why are they similar to but different from one another?

1B. Can you explain to me what a gene really is? (You can use pencil and paper in your explanation.)

1C. What is the relation between a gene and DNA ?

1D. What is the relation between DNA and chromosomes

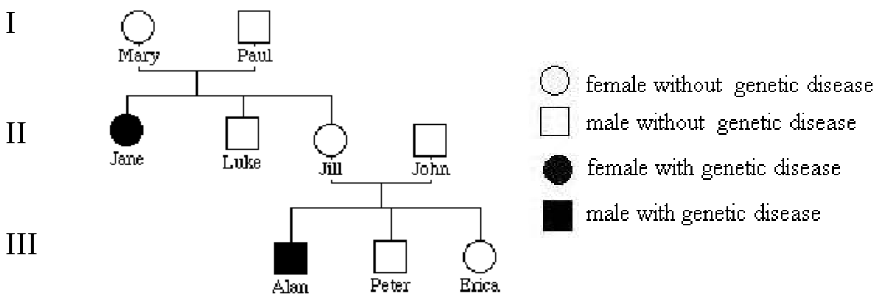
1E Explain to me how the genes get passed from parents to Dianne/other name? (Probe egg, sperms, fertilisation etc.). Why are they all girls/one boy and two girls?

1F. What do you a think a gene does ? (If answer is control characteristics etc). How does it do this (Probe "control characteristics") (If answer is "about dominant/recessive alleles" etc, then ask "why the alleles are dominant or recessive?")

*Post-instructional Interview Part 2: (all types of reasoning)*

The following pedigree chart shows the inheritance of a common genetic disease in Western Australia:

Generations:




2A: Study the pedigree chart carefully to determine the nature of inheritance of the trait (dominant or recessive)? (Type IV reasoning; explanation needs type VI)

2B: What is the genotype of (a) Jill (b) Peter? Explain fully your answers (You can use pencil and paper to work it out…) (Types IV & VI reasoning)

3C: Geneticists want to know where the gene for this genetic disease is located. Is it possible for this gene to be located on the X chromosome?

(Cue: Is it possible that the trait is sex-linked? If yes, why? If no. Why not? You can use paper and pencil to work out your reasoning…) (Types IV & VI reasoning)

Part 3:

Do you like learning genetics in the past few weeks? What do you like? How do you like the *BioLogica* activities?

Do you think that genetics that you have learnt is useful to you? If yes, how useful? How does it help you? (if the answer for tests/exams; ask how useful outside the school?)

(Extension: The interviewee is given a newspaper clipping from the *West Australia*/the *Sunday Times*/*the Australian* or science magazines on contemporary issues for comments and discussion.)

*Document A3.4.4* An Example of Teacher Interview Protocol (School A)

***First/Pre-instructional Interview***

Questions to ask:

1. Would you tell me something about teaching “genetics” as a topic in Year 10 science? (Follow-up questions e.g. Is it difficult to teach/to learn? Why? How useful is genetics as a topic in Y10 science? In what ways? Can you tell me more about this? How do you do it? )

2. Why do you want to use *BioLogica* in your teaching of genetics in Years 10?

3. (Referring to the overview of *BioLogica*) Which activities of the interactive multimedia *BioLogica* do you think would be useful for learning genetics? Why?

4. (Referring to the calendar with the planned teaching sequence incorporating *BioLogica* activities devised by the teacher) Can you explain to me how and why you devise this teaching plan?

5. What are your expectations of the learning outcomes of your students using *BioLogica*? (e.g., classroom environment… classroom management.. social interactions: peer support, teacher-student discussion, online discussion /chat…etc.)

6. Do you think that when teaching genetics in Year 10 science the teacher should stress reasoning? Why? Why not?

7. When I observed your previous lessons, you use overhead projection (or another strategy), how useful do you believe this can be in helping student learning from the lesson?

8.Other questions.

***Second/Post-instructional Teacher Interview***

Questions to ask:

1. Please tell me something about your experience teaching “genetics” as a topic in Year 10 science?

(Follow-up questions e.g. Is it difficult to teach/to learn? Why? How useful is genetics as a topic in Y10 science? In what ways? Can you tell me more about this? How do you do it .?)

2. How did you use *BioLogica* in your teaching of genetics in Years 10?

3. (Referring to the overview of *BioLogica*) Which activities of the interactive multimedia *BioLogica* did you use in your teaching. How useful for are they in learning genetics? Why?

4. (Referring to the calendar with the planned teaching sequence incorporating *BioLogica* activities devised by the teacher) Do you think about they way integrated *BioLogica* in your teaching of genetics in the past few weeks?

5. Do you think your expectations about the learning outcomes of your students using *BioLogica* have been met? (About classroom environment… classroom management.. social interactions: peer support…. Teacher-student discussion while using *BioLogica* e.g. you always brief them before using *BioLogica*)

6a. In my first interview you told me that when teaching genetics in Year 10 science the teacher should stress reasoning/problem solving. Do you think you did stress reasoning in your teaching of genetics over the past few weeks?

6b. You predicted that students can solve many more problems than they can do in the classroom. What do you think now?

7a. When I observed your previous lessons, you used different representations to teach genetics. Have you thought of how these different representations should be used more effectively to better develop students' reasoning/understanding?

7b. They liked the Dragons. Why do you think they do?

8. Do you think you would use it next year again in your teaching of genetics? Why? Why or why not?

9. Other questions, e.g., overall comments.

*Document A3.6.1* Teaching Scheme of School C

# Year 10 Science: Biology 2002

This Biology course consists of a common core, which all students will complete, followed by a choice of extension topics. All students will also complete an assignment on a set topic and a media file.The common core will be assessed by written tests.

Core Reference Text: Jacaranda Science 3.

| | |
|---|---|
| Core Tests (3) | 60% |
| Assignment | 10% |
| Media file | 10% |
| Research | 20% |

**Core Outcomes**

**<u>Cell Structure and Function</u>**

1. Describe cells as the building blocks of all living things. Define living things.

2. Describe cell organelles and their function (Revision Year 9) - nucleus, cell wall, plasma/cell membrane, cytoplasm, chloroplast, and including organelles visible under the electron microscope - mitochondrion,
ribosome, golgi body, endoplasmic reticulum, centriole.

3. Descibe the structure of a typical bacterial cell, including cell wall, circular chromosome, plasmid.

4. Identify the differences between prokaryotic (bacterial) cells and eukaryotic (animal and plant cells).

*Key words: organelles, nucleus, cell wall, plasma membrane, cytoplasm, chloroplast, mitochondrion, ribosome, golgi body, centriole, endoplasmic reticulum, electron microscope, prokaryotic, eukaryotic, plasmid.*

# Reproduction and Cell Division

5. Analyse and identify the similarities and differences between asexual and sexual reproduction.

   10.1, pages 222-223,        Remember 1 Think 3.
   10.8, pages 236-237

   List some of the advantages and disadvantages of sexual and asexual reproduction.

*Key words: asexual reproduction, cloning, parthogenesis, sexual reproduction, gametes, chromosomes.*

6. Gain knowledge of and evaluate scientific explanations of the causes of variation in living things as they reproduce by:

- Describing how the process of mitosis produces two cells with the same number and type of chromosomes
  as the parent cell (the diploid number)

- Describing how the process of meiosis produces cells (gametes) for reproduction, with half the number of chromosomes found in normal body cells (the haploid number).

- Explaining how the process of fertilisation produces a cell, the zygote, with the diploid number of chromosomes.

J.S.3 page 247 1, 2, 3, 4.
11.1, pages 248-251 Complete all Activities.

*Key words: inheritance, genetics, DNA, chromosome, gene, chromatid, centromere, mitosis, meiosis, fertilisation, zygote, diploid number, haploid number, autosomes, sex chromosomes, karyotype.*

**Core Test 1 (20%)**

# Inheritance

7. Understand how characteristics are passed from parent to offspring through the transfer of genetic material by:

- Defining alleles as different types of the same gene and use the correct notation to represent them.
- Explaining the difference between dominant and recessive alleles.
- Defining the following terms: genotype, phenotype, homozygous, heterozygous.
- Explaining the concept of co-dominance.

J.S.3 11.2 pages 252-253 Complete all Activities.

*Key words: gene, allele, recessive, dominant, genotype, phenotype, pure breeding, homozygous, heterozygous,
hybrid, co-dominance.*

8. Use mathematical techniques to determine the likely outcomes of the breeding of various individuals by:

- Explaining simple examples of the inheritance of dominant and recessive alleles.
- Calculating the probability/chance of producing particular combinations of alleles in simple genetic crosses.

J.S.3 11.3 pages 254-255 Remember 1, 2, 3, Think 1, 2, 3. All in the Family.

*Key words: Punnett square, genetic cross, probability.*

9. Understand the determination of sex in humans.

10. Explain the difference between the inheritance of genes carried on autosomes and those carried on sex chromosomes.

11. Explain the difference between identical and fraternal twins.

| | |
|---|---|
| J.S.3 11.4 pages 256-257 | Remember 1, 2, 3, 4, 5, 6, Think 1, 2, 3, 4, 5. |

*Key words: sex chromosomes, autosomes, x and y chromosomes, z and w chromosomes, identical twins, fraternal twins.*

12. Understand how mutations of genetic material can be caused.

13. Explain how mutations cause changes in genes which can be passed on from parent to offspring.

14. Describe examples of human genetic disorders and consider the effects of these conditions.

15. Interpret pedigree information on animals or plants to make inferences about dominant and recessive characteristics.

| | | |
|---|---|---|
| J.S.3 11.5 | pages 258-261 | Remember 1, 3, 4, Think 2, 4. |
| J.S 3 11.6 | pages 262-263 | Remember 1, 2, 3, 4, Think 1, 2, 3, 4, 5, 6. |
| | page 264 | Putting it all together. |
| | page 265 | Looking back 1, 2, 3, 4, 5. |

.

Key words: *mutation, mutagen, pedigree charts, karyotype, screening test, cystic fibrosis, phenylketonuria (PKU), Down's Syndrome, genetic testing*.

**Core Test 2 (20%)**

**DNA**

16. Know that chromosomes consist of a very long thread of DNA.

17. Describe the structure of deoxyribonucleic acid (DNA).

18. Name the four nitrogen bases in DNA and explain the way in which they pair.

19. Describe the process of DNA replication.

20. Explain how the genetic code is interpreted using codons or triplets. Make simple interpretations of a genetic sequence from a table of genetic code.

21. Describe (in outline only) how DNA controls the development of all an organisms characteristics.

*key words: double helix, nucleotide, nitrogen bases, genetic code, codon.*

**Core Test 3 (20%)**

## Extension Research (20%)

You may choose which area of study (being guided by your teacher) you wish to pursue. For each area you will be provided with some stimulus material to aid your research and help you to make a sensible choice. If you wish to work with a partner this must first be negotiated with your teacher.

Your research may be presented digitally, as a pamphlet, a poster, an oral presentation, or in any other manner approved by your teacher.

Human Genome Project

Genetically Manipulated Foods - points to consider might include how they are produced, advantages and disadvantages of using this technology.

Using Genetic Profiling in the diagnosis of disease. You could also consider the social issues raised by genetic profiling.

Using DNA Technology in Forensic Science, i.e. in solving crime.

Using DNA Technology to help solve environmental problems.

Survey of attitudes to the use of genetic manipulation techniques. You would need to identify a particular group you intend to survey, e.g. Year 10 students or people over 50. Your survey should be carefully planned to produce an acceptable conclusion.

Ways in which research and use of Genetic Engineering is controlled - points to consider might include laws passed by governments, organisations which monitor research and use.

Using Human Stem Cells for research. You should include some discussion of the current debate relating to the ethics of stem cell research.

History of the discovery of DNA and development of genetic engineering techniques.

DNA and protein synthesis. (Advanced)

## Media File (10%)

Make a file of five to ten items taken from the print media, television or radio during the term in which you are studying this unit, and which relate to DNA technology and genetic engineering. Your file should include a comment (short paragraph) on each item, although items referring to a common topic can be grouped together with a single comment. Record the date on which each item appeared, and for television or radio programmes you should present a summary of the programme or item.

## Assignment (10%)

Use the library and internet resources to describe:

the stages in genetically engineering a bacterium to produce substances useful to humans. Key words to use include plasmid, restriction enzyme, ligase.

examples of the use of genetic engineering in medicine, agriculture and industry.

Your assignment should be no more than five hundred words and should include a bibliography of print material and internet sites used.

*Document A3.6.2* Andrea's *Monohybrid* Log File (School C)


```
<log>
  <user> Andrea </user>
  <action>
    <date> 2002.06.11.19.05.23 06/11/02 | 19:05:23 </date>
    START OF ACTIVITY
  </action>
      <action>
        <date> 2002.06.11.19.05.56 06/11/02 | 19:05:56 </date>
        Asked for practice dragon to check out tails rule.
      </action>
  <action>
    <date> 2002.06.11.19.07.01 06/11/02 | 19:07:01 </date>
    Made a baby without looking at the chromosomes.
  </action>
    <action>
      <date> 2002.06.11.19.07.17 06/11/02 | 19:07:17 </date>
      Looked at father's gametes in meiosis view.
    </action>
    <action>
      <date> 2002.06.11.19.07.26 06/11/02 | 19:07:26 </date>
      Looked at mother's gametes in meiosis view.
    </action>
  <action>
    <date> 2002.06.11.19.07.37 06/11/02 | 19:07:37 </date>
    Made a fancy-tailed baby. Looked at chromosomes.
  </action>
    <action>
      <date> 2002.06.11.19.07.56 06/11/02 | 19:07:56 </date>
      Looked at father's gametes in meiosis view.
    </action>
    <action>
      <date> 2002.06.11.19.08.00 06/11/02 | 19:08:00 </date>
      Looked at mother's gametes in meiosis view.
    </action>
  <action>
    <date> 2002.06.11.19.08.09 06/11/02 | 19:08:09 </date>
    Made a plain-tailed baby while looking for one.
  </action>
  <action>
    <date> 2002.06.11.19.08.46 06/11/02 | 19:08:46 </date>
    Made the first baby in pedigree view. It's got a fancy tail, so we're looking for a plain-tailed one.
  </action>
  <action>
    <date> 2002.06.11.19.09.05 06/11/02 | 19:09:05 </date>
    Another fancy-tailed offspring.
```

```
</action>
<action>
    <date> 2002.06.11.19.09.15 06/11/02 | 19:09:15 </date>
    Got a plain-tailed dragon in 3 tries. Next cross will have 30 offspring.
</action>
<action>
    <date> 2002.06.11.19.09.35 06/11/02 | 19:09:35 </date>
    Created a total of 33 offspring, of which 15 have plain tails and 18 have fancy tails.
</action>
<action>
    <date> 2002.06.11.19.11.01 06/11/02 | 19:11:01 </date>
    Got the zygotes right in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.06.11.19.11.28 06/11/02 | 19:11:28 </date>
    Selected the right zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.06.11.19.12.15 06/11/02 | 19:12:15 </date>
    Made first cross in second pedigree view.
</action>
<action>
    <date> 2002.06.11.19.13.03 06/11/02 | 19:13:03 </date>
    Got gametes and zygotes right in tt X TT Punnett square.
</action>
<action>
    <date> 2002.06.11.19.13.09 06/11/02 | 19:13:09 </date>
    Selected the right zygotes (none) in the tt X TT Punnett square.
</action>
<action>
    <date> 2002.06.11.19.13.30 06/11/02 | 19:13:30 </date>
    Answered RIGHT: 'mixture of plain-tailed and fancy-tailed offspring' from tt X TT.
</action>
<action>
    <date> 2002.06.11.19.13.39 06/11/02 | 19:13:39 </date>
    Produced F1 offspring in third pedigree view (all fancy-tailed).
</action>
<action>
    <date> 2002.06.11.19.13.57 06/11/02 | 19:13:57 </date>
    Crossed two F1 offspring in third pedigree view. 8 of the F2 offspring have plain tails.
</action>
<action>
    <date> 2002.06.11.19.14.33 06/11/02 | 19:14:33 </date>
    Selected the 'tt' box in the tT X tT Punnett square.
</action>
<action>
    <date> 2002.06.11.19.15.02 06/11/02 | 19:15:02 </date>
    Answered RIGHT: 'only plain-tailed offspring' from tt X tt cross.
```

```
    </action>
        <action>
          <date> 2002.06.11.19.15.16 06/11/02 | 19:15:16 </date>
          Start of Summary node.
        </action>
        <action>
          <date> 2002.06.11.19.17.58 06/11/02 | 19:17:58 </date>
          Read first screen in Summary.
        </action>
        <action>
          <date> 2002.06.11.19.18.04 06/11/02 | 19:18:04 </date>
          Read second screen in Summary.
        </action>
        <action>
          <date> 2002.06.11.19.18.06 06/11/02 | 19:18:06 </date>
          Read third screen in Summary.
        </action>
    <action>
      <date> 2002.06.11.19.18.06 06/11/02 | 19:18:06 </date>
      END OF ACTIVITY
    </action>
  </log>
```

*Document A3.7.1* Helena's *Monohybrid* Log File on 6 August 2002 (School D)


```
<log>
  <user> Helena </user>
  <action>
    <date> 2002.08.06.16.02.05 08/06/02 | 16:02:05 </date>
    START OF ACTIVITY
  </action>
      <action>
        <date> 2002.08.06.16.03.44 08/06/02 | 16:03:44 </date>
        Asked for practice dragon to check out tails rule.
      </action>
      <action>
        <date> 2002.08.06.16.04.08 08/06/02 | 16:04:08 </date>
        Asked for practice dragon to check out tails rule.
      </action>
  <action>
    <date> 2002.08.06.16.07.14 08/06/02 | 16:07:14 </date>
    Made a baby without looking at the chromosomes.
  </action>
      <action>
        <date> 2002.08.06.16.07.32 08/06/02 | 16:07:32 </date>
        Asked for help in Meiosis.
      </action>
    <action>
      <date> 2002.08.06.16.07.50 08/06/02 | 16:07:50 </date>
      Looked at mother's, father's and baby's chromosomes in meiosis view.
    </action>
    <action>
      <date> 2002.08.06.16.09.02 08/06/02 | 16:09:02 </date>
      Looked at gametes in fertilization view.
    </action>
    <action>
      <date> 2002.08.06.16.09.30 08/06/02 | 16:09:30 </date>
      Looked at mother's, father's and baby's chromosomes in meiosis view.
    </action>
    <action>
      <date> 2002.08.06.16.10.43 08/06/02 | 16:10:43 </date>
      Looked at father's gametes in meiosis view.
    </action>
    <action>
      <date> 2002.08.06.16.11.03 08/06/02 | 16:11:03 </date>
      Looked at mother's gametes in meiosis view.
    </action>
    <action>
      <date> 2002.08.06.16.11.30 08/06/02 | 16:11:30 </date>
      Looked at father's gametes in meiosis view.
    </action>
```

```
    <action>
        <date> 2002.08.06.16.11.43 08/06/02 | 16:11:43 </date>
        Made a plain-tailed baby and looked at chromosomes.
    </action>
        <action>
            <date> 2002.08.06.16.11.55 08/06/02 | 16:11:55 </date>
            Looked at mother's gametes in meiosis view.
        </action>
        <action>
            <date> 2002.08.06.16.12.18 08/06/02 | 16:12:18 </date>
            Looked at mother's gametes in meiosis view.
        </action>
        <action>
            <date> 2002.08.06.16.12.30 08/06/02 | 16:12:30 </date>
            Looked at father's gametes in meiosis view.
        </action>
    <action>
        <date> 2002.08.06.16.12.37 08/06/02 | 16:12:37 </date>
        Made a fancy-tailed baby while looking for one.
    </action>
    <action>
        <date> 2002.08.06.16.12.58 08/06/02 | 16:12:58 </date>
        Made the first baby in pedigree view. It's got a fancy tail, so we're looking for a plain-tailed one.
    </action>
    <action>
        <date> 2002.08.06.16.13.45 08/06/02 | 16:13:45 </date>
        Got a plain-tailed dragon in 2 tries. Next cross will have 30 offspring.
    </action>
    <action>
        <date> 2002.08.06.16.14.10 08/06/02 | 16:14:10 </date>
        Created a total of 32 offspring, of which 18 have plain tails and 14 have fancy tails.
    </action>
    <action>
        <date> 2002.08.06.16.14.56 08/06/02 | 16:14:56 </date>
        Made a cross but not from the original parents.
    </action>
    <action>
        <date> 2002.08.06.16.15.05 08/06/02 | 16:15:05 </date>
        Made a cross but not from the original parents.
    </action>
    <action>
        <date> 2002.08.06.16.15.33 08/06/02 | 16:15:33 </date>
        Created a total of 62 offspring, of which 36 have plain tails and 26 have fancy tails.
    </action>
    <action>
        <date> 2002.08.06.16.15.39 08/06/02 | 16:15:39 </date>
        Created a total of 92 offspring, of which 48 have plain tails and 44 have fancy tails.
```

</action>
<action>
<date> 2002.08.06.16.15.43 08/06/02 | 16:15:43 </date>
Created a total of 122 offspring, of which 56 have plain tails and 66 have fancy tails.
</action>
<action>
<date> 2002.08.06.16.17.02 08/06/02 | 16:17:02 </date>
Looked Mom's chromosomes in first Punnett square.
</action>
<action>
<date> 2002.08.06.16.17.50 08/06/02 | 16:17:50 </date>
Got the zygotes right in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.40 08/06/02 | 16:18:40 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.41 08/06/02 | 16:18:41 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.54 08/06/02 | 16:18:54 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.55 08/06/02 | 16:18:55 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.57 08/06/02 | 16:18:57 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.18.58 08/06/02 | 16:18:58 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.19.05 08/06/02 | 16:19:05 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.19.08 08/06/02 | 16:19:08 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
<date> 2002.08.06.16.19.11 08/06/02 | 16:19:11 </date>
Selected the wrong zygotes in the tt X Tt Punnett square.

```
</action>
<action>
    <date> 2002.08.06.16.19.13 08/06/02 | 16:19:13 </date>
    Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.19.14 08/06/02 | 16:19:14 </date>
    Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.19.15 08/06/02 | 16:19:15 </date>
    Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.19.17 08/06/02 | 16:19:17 </date>
    Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.19.23 08/06/02 | 16:19:23 </date>
    Selected the wrong zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.19.48 08/06/02 | 16:19:48 </date>
    Selected the right zygotes in the tt X Tt Punnett square.
</action>
<action>
    <date> 2002.08.06.16.20.50 08/06/02 | 16:20:50 </date>
    Made first cross in second pedigree view.
</action>
<action>
    <date> 2002.08.06.16.24.04 08/06/02 | 16:24:04 </date>
    Got gametes wrong in tt X TT Punnett square.
</action>
<action>
    <date> 2002.08.06.16.25.17 08/06/02 | 16:25:17 </date>
    Got gametes and zygotes right in tt X TT Punnett square.
</action>
<action>
    <date> 2002.08.06.16.25.38 08/06/02 | 16:25:38 </date>
    Selected one or more zygotes in the tt X TT Punnett square.
</action>
<action>
    <date> 2002.08.06.16.25.48 08/06/02 | 16:25:48 </date>
    Selected the right zygotes (none) in the tt X TT Punnett square.
</action>
<action>
    <date> 2002.08.06.16.26.28 08/06/02 | 16:26:28 </date>
    Answered WRONG: 'only fancy-tailed offspring' from tt X TT.
```

```
    </action>
    <action>
        <date> 2002.08.06.16.26.35 08/06/02 | 16:26:35 </date>
        Produced F1 offspring in third pedigree view (all fancy-tailed).
    </action>
    <action>
        <date> 2002.08.06.16.26.43 08/06/02 | 16:26:43 </date>
        END OF ACTIVITY
    </action>
</log>
```

*Document A3.7.2* May's *Monohybrid* Log File (part) on 6 August 2002 (School D)

```
<log>
   <user> May </user>
   <action>
      <date> 2002.08.06.16.02.04 08/06/02 | 16:02:04 </date>
      START OF ACTIVITY
   </action>
         <action>
            <date> 2002.08.06.16.04.22 08/06/02 | 16:04:22 </date>
            Asked for practice dragon to check out tails rule.
         </action>
   <action>
      <date> 2002.08.06.16.06.08 08/06/02 | 16:06:08 </date>
      Made a baby without looking at the chromosomes.
   </action>
   <action>
      <date> 2002.08.06.16.07.14 08/06/02 | 16:07:14 </date>
      Made a fancy-tailed baby. Still not looking at chromosomes.
   </action>
   <action>
      <date> 2002.08.06.16.07.34 08/06/02 | 16:07:34 </date>
      Made a plain-tailed baby. Still not looking at chromosomes.
   </action>
   <action>
      <date> 2002.08.06.16.07.48 08/06/02 | 16:07:48 </date>
      Made a fancy-tailed baby. Still not looking at chromosomes.
   </action>
      <action>
         <date> 2002.08.06.16.08.52 08/06/02 | 16:08:52 </date>
         Looked at mother's gametes in meiosis view.
      </action>
      <action>
         <date> 2002.08.06.16.09.04 08/06/02 | 16:09:04 </date>
         Looked at mother's gametes in meiosis view.
      </action>
      <action>
         <date> 2002.08.06.16.09.20 08/06/02 | 16:09:20 </date>
         Looked at father's gametes in meiosis view.
      </action>
   <action>
      <date> 2002.08.06.16.09.34 08/06/02 | 16:09:34 </date>
      Made a plain-tailed baby and looked at chromosomes.
   </action>
   <action>
      <date> 2002.08.06.16.09.53 08/06/02 | 16:09:53 </date>
      Made a plain-tailed baby while looking for a fancy-tailed one.
```

```
46 </action>
47 <action>
48 <date> 2002.08.06.16.10.05 08/06/02 | 16:10:05 </date>
49 Made a fancy-tailed baby while looking for one.
50 </action>
51 <action>
52 <date> 2002.08.06.16.13.02 08/06/02 | 16:13:02 </date>
53 Made the first baby in pedigree view. It's got a plain tail, so we're looking for a fancy-
54 tailed one.
55 </action>
56 <action>
57 <date> 2002.08.06.16.13.17 08/06/02 | 16:13:17 </date>
58 Another plain-tailed offspring.
59 </action>
60 <action>
61 <date> 2002.08.06.16.13.22 08/06/02 | 16:13:22 </date>
62 Got a fancy-tailed dragon in 3 tries. Next cross will have 30 offspring.
63 </action>
64 <action>
65 <date> 2002.08.06.16.14.06 08/06/02 | 16:14:06 </date>
66 Created a total of 33 offspring, of which 19 have plain tails and 14 have fancy tails.
67 </action>
68 <action>
```

Line 80-295 omitted

*Document A3.7.3* Kath's *Meiosis* Log File on 5 August 2002 (School D)


```
<log>
  <user> Kath </user>
  <action>
    <date> 2002.08.05.14.52.04 08/05/02 | 14:52:04 </date>
    START OF ACTIVITY
  </action>
  <action>
    <date> 2002.08.05.14.58.06 08/05/02 | 14:58:06 </date>
    Student made baby dragon as instructed.
  </action>
  <action>
    <date> 2002.08.05.14.58.11 08/05/02 | 14:58:11 </date>
    The student presumably made any kind of baby dragon.
  </action>
    <action>
      <date> 2002.08.05.15.02.56 08/05/02 | 15:02:56 </date>
      Student made baby boy dragon instead of a baby girl dragon.
    </action>
  <action>
    <date> 2002.08.05.15.03.20 08/05/02 | 15:03:20 </date>
    Student made baby girl dragon as instructed.
  </action>
    <action>
      <date> 2002.08.05.15.03.46 08/05/02 | 15:03:46 </date>
      Student did not make baby boy dragon as instructed.  Made baby girl.
    </action>
    <action>
      <date> 2002.08.05.15.03.59 08/05/02 | 15:03:59 </date>
      Student did not make baby boy dragon as instructed.  Made baby girl.
    </action>
    <action>
      <date> 2002.08.05.15.04.14 08/05/02 | 15:04:14 </date>
      Student did not make baby boy dragon as instructed.  Made baby girl.
    </action>
    <action>
      <date> 2002.08.05.15.04.27 08/05/02 | 15:04:27 </date>
      Student did not make baby boy dragon as instructed.  Made baby girl.
    </action>
    <action>
      <date> 2002.08.05.15.04.41 08/05/02 | 15:04:41 </date>
      Student did not make baby boy dragon as instructed.  Made baby girl.
    </action>
  <action>
```

```
        <date> 2002.08.05.15.05.01 08/05/02 | 15:05:01 </date>
        Student made baby boy dragon as instructed.
    </action>
        <action>
            <date> 2002.08.05.15.05.43 08/05/02 | 15:05:43 </date>
            Student made dead dragon.
        </action>
        <action>
            <date> 2002.08.05.15.06.01 08/05/02 | 15:06:01 </date>
            Student made LIVE baby girl.  Supposed to make LIVE baby boy.
        </action>
    <action>
        <date> 2002.08.05.15.06.12 08/05/02 | 15:06:12 </date>
        Student made LIVE baby boy as instructed.
    </action>
        <action>
            <date> 2002.08.05.15.06.27 08/05/02 | 15:06:27 </date>
            Dragon is alive, but not the right gender and not the right number of legs.
        </action>
        <action>
            <date> 2002.08.05.15.06.40 08/05/02 | 15:06:40 </date>
            Dragon is alive, but not the right gender and not the right number of legs.
        </action>
        <action>
            <date> 2002.08.05.15.06.49 08/05/02 | 15:06:49 </date>
            Made a dead dragon.
        </action>
        <action>
            <date> 2002.08.05.15.06.59 08/05/02 | 15:06:59 </date>
            Made a dead dragon.
        </action>
        <action>
            <date> 2002.08.05.15.07.05 08/05/02 | 15:07:05 </date>
            Dragon is alive, but not the right gender and not the right number of legs.
        </action>
        <action>
            <date> 2002.08.05.15.07.14 08/05/02 | 15:07:14 </date>
            Made the right number of legs, but not a boy.
        </action>
        <action>
            <date> 2002.08.05.15.07.24 08/05/02 | 15:07:24 </date>
            Made the right number of legs, but not a boy.
        </action>
    <action>
        <date> 2002.08.05.15.07.31 08/05/02 | 15:07:31 </date>
        Correct.  Made a live male dragon with two legs.
    </action>
```

```
<action>
    <date> 2002.08.05.15.07.51 08/05/02 | 15:07:51 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.00 08/05/02 | 15:08:00 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.07 08/05/02 | 15:08:07 </date>
    Incorrect.  Made a dead dragon.
</action>
<action>
    <date> 2002.08.05.15.08.12 08/05/02 | 15:08:12 </date>
    Incorrect.  Made a dead dragon.
</action>
<action>
    <date> 2002.08.05.15.08.21 08/05/02 | 15:08:21 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.28 08/05/02 | 15:08:28 </date>
    Incorrect.  Made a dead dragon.
</action>
<action>
    <date> 2002.08.05.15.08.37 08/05/02 | 15:08:37 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.45 08/05/02 | 15:08:45 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.52 08/05/02 | 15:08:52 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.08.59 08/05/02 | 15:08:59 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.09.05 08/05/02 | 15:09:05 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
<action>
    <date> 2002.08.05.15.09.16 08/05/02 | 15:09:16 </date>
    Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
</action>
```

```
        <action>
            <date> 2002.08.05.15.09.24 08/05/02 | 15:09:24 </date>
            Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
        </action>
        <action>
            <date> 2002.08.05.15.09.47 08/05/02 | 15:09:47 </date>
            Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
        </action>
        <action>
            <date> 2002.08.05.15.09.53 08/05/02 | 15:09:53 </date>
            Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
        </action>
        <action>
            <date> 2002.08.05.15.09.58 08/05/02 | 15:09:58 </date>
            Incorrect.  Made a female dragon with a plain tail.  Should be female with a fancy tail.
        </action>
    <action>
        <date> 2002.08.05.15.10.07 08/05/02 | 15:10:07 </date>
        Correct.  Made a female dragon with a fancy tail.
    </action>
        <action>
            <date> 2002.08.05.15.10.26 08/05/02 | 15:10:26 </date>
            Made a dead dragon.
        </action>
        <action>
            <date> 2002.08.05.15.10.31 08/05/02 | 15:10:31 </date>
            Dragon is alive, but not the right gender and not the right number of legs.
        </action>
        <action>
            <date> 2002.08.05.15.10.41 08/05/02 | 15:10:41 </date>
            Dragon is alive, but not the right gender and not the right number of legs.
        </action>
        <action>
            <date> 2002.08.05.15.10.45 08/05/02 | 15:10:45 </date>
            Made a dead dragon.
        </action>
    <action>
        <date> 2002.08.05.15.10.54 08/05/02 | 15:10:54 </date>
        Correct.  Made a live male dragon with two legs.
    </action>
        <action>
            <date> 2002.08.05.15.11.30 08/05/02 | 15:11:30 </date>
            Incorrect.  Made a dead dragon.
        </action>
        <action>
            <date> 2002.08.05.15.11.35 08/05/02 | 15:11:35 </date>
            Incorrect.  Made a dead dragon.
        </action>
```

```
<action>
    <date> 2002.08.05.15.11.42 08/05/02 | 15:11:42 </date>
    Correct.  Made a female dragon with a fancy tail.
</action>
    <action>
        <date> 2002.08.05.15.11.54 08/05/02 | 15:11:54 </date>
        Made a dead dragon.
    </action>
    <action>
        <date> 2002.08.05.15.12.01 08/05/02 | 15:12:01 </date>
        Dragon is alive, but not the right gender and not the right number of legs.
    </action>
    <action>
        <date> 2002.08.05.15.12.10 08/05/02 | 15:12:10 </date>
        Dragon is alive, but not the right gender and not the right number of legs.
    </action>
    <action>
        <date> 2002.08.05.15.12.15 08/05/02 | 15:12:15 </date>
        Made a dead dragon.
    </action>
    <action>
        <date> 2002.08.05.15.12.20 08/05/02 | 15:12:20 </date>
        Made a dead dragon.
    </action>
<action>
    <date> 2002.08.05.15.12.27 08/05/02 | 15:12:27 </date>
    Correct.  Made a live male dragon with two legs    </action>
<action>
    <date> 2002.08.05.15.14.43 08/05/02 | 15:14:43 </date>
    END OF ACTIVITY
</action>
```