Science and Mathematics Education Centre

An Investigation of the Effectiveness of Using Analogies in Teaching and Learning Scientific Concepts

Florence Nesamony Ballard

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Abstract

Educators are constantly looking for effective teaching strategies, which can engender a favourable conceptual change in students within a constructivist paradigm. Teaching science with analogy could be one of such instructional strategies found effective in motivating students by providing them with familiar and tangible visual stimuli taken from the students' world to provide a basis for bridging and promoting associations between a known and an unknown realm. In this way, a complex, abstract concept can be made simple and interesting by reducing or eliminating students' misconceptions and alternative frameworks. This study was undertaken to find out whether a systematically planned and presented analogy using the FAR Guide has the capacity to enhance student understanding, remove misconceptions and improve higher order thinking. The sample consisted of 154 students from a state high school in Queensland, Australia, which caters for learners coming from 50 different ethnic groups settled in Australia. Five different analogies were presented to students in grades 8, 11 and 12, aged 12-18 years, as a component of their science, chemistry and biology lessons, respectively. This cohort consisted of 76 boys and 78 girls and the effectiveness of these analogies was studied by collecting qualitative and quantitative data. The five chosen analogies were designed cautiously to eliminate and minimise any discrepancy or ambiguity between the analog and target. All had qualities, which were appealing to the students. They were deliberately made to appear different from the regular 'chalk and talk' method and all the visuals were made colourful and attractive with appropriate titles, labels and short notes; thus gaining maximum attention to perceive the analog-target relationship. Two examples relating to real life situations, an outdoor-game, a cut and paste paper craft activity and a partly animated Power Point presentation were presented as analogies. The diagnostic instruments were carefully structured so that the multiple choices would readily bring out the understanding of the concept and misconceptions held by the students, both prior to and after the presentation of the analogies. The pretest results were not revealed to the students until the posttest was completed and evaluated. This research followed specific stages in addressing the research questions and did not predetermine or delimit the direction the investigation took in its course. A paired samples t-test conducted to evaluate the impact of the instruction showed a statistically significant increase in the scores from the pretest to posttest, indicating improved understanding, an increase in higher order thinking and a considerable decrease in misconceptions and alternative frameworks.

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Teaching will give you daily an unbelievable roller coaster ride from the depths of total frustration to the highs of incredible rewards. In most cases, you will never know the results of your actions. It is a profession that is given little respect and lots of criticism. Everyone is an expert and quite willing to tell you so. Rarely do you receive thanks but with one tiny look, word, or action a student can inspire and reward you beyond all expectation and you find yourself thinking maybe I will come back tomorrow!!

Schmier in Random Thoughts (2000)

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Chapter 1

Introduction and Overview

1. 0 Introduction

Chapter 1 begins with a personal teaching experience given under the rationale for the study (section 1.1). This experience initiated my interest in teaching science with analogies and led to a search to get supporting literature to know more about analogies so that I could do a systematic study of using analogies to simplify complex science concepts for the understanding of students (section 1.2). The purpose of the study and objectives are stated in this chapter (sections 1.3 and 1.4). The research design contains the action research undertaken to find out how science teaching could be improved for the benefit of the students (section 1.5). This chapter also includes my search to find a suitable diagnostic tool to test the knowledge and understanding of the students before and after the presentation of the analogies (section 1.6). The significance of the study and its relevance to educating students has been included (section 1.7). A brief explanation under methodology states that since every analogy has unique characteristics and mode of presentation, it is impossible to write one common methodology. Therefore the methodology specific to each analogy has been included in each chapter (section 1.7). The chapter concludes with the summary (section 1.8).

1.1 Rationale for the Study

It was a biology lesson dealing with animal anatomy and physiology. The chosen topic was the human nervous system. The students had already observed a sheep's brain, heart and lungs during their practical session a week earlier. They touched and felt the tough outer covering of the brain and observed the rich blood supply. The acronym 'DAP' was well received to remember the three meninges in order, namely Duramater, Arachnoid membrane and Piamater. A diagram on the board, which showed the transverse section of the brain, seemed to capture their interest. Unfortunately all these helped very little in understanding the meninges for many students in the class. In sheer frustration, the teacher's brain was desperately looking for something to make this concept understandable. This resulted in describing the meninges as something similar to the plastic shopping bags from Woolworths. They were told, 'Imagine the brain being covered with three plastic bags, the outer one being a tough bag, the next one with a network of blood vessels embedded in it and the innermost bag lining the brain. The space between the second and the third bag is holding a fluid, which is known as the cerebro-spinal fluid. Substances are constantly oozing out of the blood vessels from the blood into this fluid and the fluid passes these substances on to the third membrane, through which the substances pass into the brain to nourish the nerve cells'. The explanation is not strictly an analogy; rather a blend of an analogy and reality.

The pleasant surprise on the following day was that the students' responses confirmed that they had grasped the idea. The purpose of introducing an analogy was achieved. After the class was dismissed, a student came up and said that she saw a brain with plastic coverings in her dream on the same night after the lesson was taught! She was quite excited about the visual created by her own brain, while her conscious mind was asleep; a mental process in which the details unfurled, helping her to grasp what was taught. This experience gave the awareness that an analogy could be a powerful tool in teaching and learning science and this initiated the interest in analogies. From then on, many analogies were incorporated in daily teaching, but with caution. It was ensured that it didn't introduce or augment alternative conceptions. The common observation is that students assimilate the given information easily, if it suits their intellectual level and develop an inquiring mind for further construction of relevant knowledge.

When students fail to grasp the information holistically, alternative conceptions develop and this will inhibit their ability to construct further. Alternative conceptions, whether present prior to learning or developed during learning, make students' learning deficient. The targeted students fail to achieve what was intended by the educator. Many students may even carry these alternative conceptions beyond school. Moreover, if a teacher wishes to cater for the needs of all the students under his/her care, and considering that a class consists of many students at various intellectual levels with various and varied interests, he/she should look at providing information in more than one way. An enthusiastic teacher seeks opportunities to include innovative and stimulating learning experiences, which have the potential to captivate the students with sustained interest. He/she would also look at making learning more tangible and meaningful to all students. It is also prudent to direct the students to be open minded and flexible in their thinking, while they apply their knowledge to solve problems. Such a directive will ensure that they exploit their acquired knowledge to the maximum in their daily life situations and future occupations, reaping great rewards. Deep understanding of concepts in science is a requirement to optimise a student's accomplishment in the chosen discipline. It is worthwhile to find out whether analogies would serve as fitting vehicles to transfer information and provide the required level of deep understanding of scientific concepts.

1.2 Teaching with analogies

It is generally recognized that analogies can facilitate the generation of meaning through a constructivist pathway (Duit, 1991a). The Teaching With Analysis (TWA) model (Glynn, Duit, & Thiele, 1995) provides guidelines for using analogies. The purpose of using analogies is to transfer ideas from a familiar concept (analog) to an unfamiliar one (target). Though the TWA model paved the way to refined approaches in teaching with analogies, the model itself was not always successful in its application due to the number of steps involved in its implementation. Search for 'a simpler, and … more effective and teacher-friendly teaching model of analogy teaching' (Treagust, Venville, Harrison, Stocklmayer, & Thiele, 1993, p. 91), brought out the FAR Guide, and was given the acronym for Focus, Action and Reflection. The students concentrate on the target and analog (Focus), look at the features of both the target and analog to draw similarities and dissimilarities (Action) and draw their conclusions (Reflection). The teacher facilitates the above operations until the students learn to use analogies effectively by sifting through the unshared attributes and focusing on the essential shared attributes for correlation.

The incorporation of the FAR Guide is likely to be advantageous in teaching science to promote better use of analogies and better understanding of scientific concepts. However, the effectiveness of the use of the FAR Guide is yet to be fully demonstrated (Treagust, Harrison & Venville, 1998). Teaching by using analogies ties into the fact that Generation Y has shown a preference for the use of elaboration strategies to help build meaning by constructing relationships within the material to be learnt or between prior knowledge/experience and new materials (Faust, Ginno, Laherty & Manuel, 2001). Recent work in developmental psychology demonstrates that children are able to solve problems using relational similarity (i.e. reason by analogy) from an early age, provided that they have a relevant knowledge base (Goswami, 2001). Analogy making is at the core of recognition (Hofstadter, 2001). A report from the Akron Global Polymer Academy (AGPA, 2001) observed 'Using analogies' as one of the best teaching practices in P-16 Education Initiatives in the United States. Calik, Ayas and Coll (2009, p. 269) are of the opinion that 'even though students may not construct their understanding properly after completing the analogy activity, in the course of time, the activity may afford the conditions for students to continue this construction process in their mind so that he/she may have continued to construct his/her understanding'. According to them, interaction between peers might enhance this construction process, finally leading to a favourable conceptual change.

Further, the AGPA (2001) states that some research studies conducted on the use of analogies prior to the 1980s indicate that using analogies assists in concept development, when students have alternative conceptions about a particular concept. They seem to believe that research in this area tends to be qualitative in nature, and the conceptual change that occurs may not result in higher scores on multiple choice science tests of facts and concepts. This speculation is particularly significant in the area of research and offers sufficient motivation to research further and conclude whether a systematic method of teaching science with analogies would engender conceptual change in students or not. This necessitates action research, employing diverse research designs for a significant period of time. This research study is one of such attempts, which investigated the effectiveness of using a systematic approach, the FAR guide, to present analogies to teach and learn scientific concepts and the role they play in conceptual change in students. This study investigated whether the analogies had the potential to: a) enhance student understanding of scientific concepts, b) reduce the incidence of alternative frameworks, and c) enhance the ability of students to extend their thinking to higher levels.

1.3 Purpose of the Study and Objectives

To investigate the effectiveness of using the FAR guide to present analogies to teach and learn scientific concepts.

Objective 1: To investigate whether the chosen analogies have the potential to enhance student understanding of science concepts.

Research questions:

1a. What are the analogies that will correspond with the listed concepts and favour transfer?

1b. What are the features in the analog that will make the target easier to grasp?

1c. Do the analogies play a significant role in promoting understanding of the target?

Objective 2: To investigate whether the analogies have the potential to reduce incidence of alternative frameworks.

Research questions:

2a. What are the common alternative conceptions about the chosen concepts in students?

2b. What role did analogies play in minimising or eliminating the above alternative conceptions?

Objective 3: To investigate whether the analogies have the potential to extend student thinking to higher levels.

Research questions:

3a. Do analogies simulate thinking in students?

3b. Do analogies help to bring about conceptual change in students?

3c. What are the evidences that show that the introduced analogies did or did not enhance students' thinking processes to reach higher order thinking levels?

1.4 Research Design

The incentive to investigate and find a solution for students' lack of motivation and interest in science came from the students of North Queensland. Up to this time I had enjoyed a gratifying career in teaching senior biology and science overseas, where the students' results were outstanding and extremely rewarding at the end of each year. It was frustrating, not knowing where to start and where to end, due to the lack of students' interest in science and fundamental scientific knowledge in junior and senior high school students. The first attempt was to conduct a brief study to get to know the grade 8 students' conceptions on the importance of science. This investigation was decided after a parent-teacher interview in 2001. During the interview, a parent said that she didn't find any relevance in her son learning science, because she felt that he wouldn't need scientific knowledge to carry him through in the future. This gave the perception that this mother had the potential to influence her son negatively due to her limited knowledge on this issue and that in turn can have a negative impact on her son in learning science. She was not the only parent, who didn't offer any support or encouragement to a child to learn science. This prompted the preparation of a questionnaire to know the level of scientific knowledge of the students taught at the time; also to find out whether they were aware of science and its relevance to our daily life. During the discussion after the test, it came as a surprise to many of them that science and their daily life are inseparable and how much human life depended on the contributions from science and scientists.

Two other investigations were carried out in 2001 to find out whether the students had the ability to think 'scientifically'. The students were given a scientific concept, in this case, the Particle theory, as a visual. This was followed by the students' visualisation of certain situations based on the Particle Theory and drawing them on a given paper. The left side of the sheet showed how solids, liquids and gases would look if they were to look at them with 'special eyes'. The right side showed a few statements such as the formation of clouds, wet clothes drying on a clothesline and a few others. The students were asked to think and imagine how these processes would occur in nature, if matter were to exist as particles. They were then required to draw diagrams for each situation based on the Particle Theory. The second part contained a few problem-solving situations, which required either drawing the processes as visuals or writing brief notes as the steps involved in the process. This was followed by short response-questions. All the given questions had one thing in common; the students had to think 'scientifically', imagine and visualise the process mentally before they drew or wrote. The conversation with the students following this activity helped to realise that very little thinking went into learning science at primary level and this was further confirmed by their responses. The students hardly remembered what they had learnt in science at primary level; 47.5% remembered the demonstration of a water rocket and electric circuits and the rest didn't remember anything related to science at all. The students seemed to enjoy the activity on the Particle Theory because they had the freedom to draw whatever pleased them in order to express what they had understood. This investigation was valuable since it revealed the students' line of thinking in understanding the concept to a certain extent.

If a student did not comprehend the concept as a whole, the drawn visual was chaotic and clearly revealed that the teacher had to intervene, simplify or review the concept and reinforce as early as possible so that the misconception did not get stored in students' long term memory. The discussion after this activity elucidated the expectation to the students in completing the activity. It was hoped that this activity would initiate the students to use or enhance their thinking skills in the future. Unfortunately there was no opportunity to explore the effect on the thinking of the students further.

The second study involved concept maps and this showed how a student associates a scientific concept with their existing knowledge and real world situations. This activity was an 'eye opener' and helped to identify the students, who had an aptitude for science and higher order thinking potentials. Further, at the end of 2001, grade 10 was given a questionnaire to give practicable suggestions based on their learning experiences. It was anticipated that it would help to plan future teaching to motivate the junior students to learn science with sustained interest and active participation. It was unsuccessful.

The above simple studies were followed by another investigation in 2002. This was based on Gardner's (1983) Theory of Multiple Intelligences, using the same questionnaire developed by Gardner. The aim of the study was to recognise my grade 8 students' strengths and weaknesses as Multiple Intelligences, to find out whether there was any correlation between a student's multiple intelligences and student-achievement in science and whether there was any relationship between a particular Intelligence and the level of academic achievement in science. The questionnaire was administered to 32 students and the results were analysed. The analysis of the results revealed that there was not enough evidence to show that there was a definite correlation between a particular Intelligence in a student and his/her academic achievement in science. However, the students, who scored higher averages in the Multiple Intelligences questionnaire, were the ones, who generally performed well in science. The students who scored high in the Multiple Intelligences Survey but lower averages in science class tests had specific difficulties such as severe literacy problems. The factors which led them to obtain low marks in their assessments were either due to the inability to understand the given questions or failure to express ideas clearly and appropriately or failure to submit their assignments for evaluation on time. Since the class had only 32 students, the results cannot be considered as viable statistically. Though the study failed to prove that the multiple intelligences in an individual had a definite bearing on his/her academic performance in science, there was enough substantiation in the classroom to show that the students who had scored higher average MI scores had the ability to tackle problems in science more effectively than the others with lower scores. Awareness of intelligences in students could benefit teachers in knowing the strengths and weaknesses recognised as multiple intelligences. This knowledge is likely to enable a teacher to create balanced individual educational plans (IEP) or modify the existing ones to make learning activities more productive and profitable to students. All these investigations, though conducted on a smaller scale within a short period of time, gave an insight into students' thinking potentials with regard to learning scientific concepts. Many low achievers were able to think productively when adequately stimulated and facilitated. Inadequate English language skills affected a students' expression, resulting in low scores in class tests, but not their thinking skills. This series of action research activities formed the basis for further research; in particular, I was induced with an eagerness to become involved in educational research to find more effective teaching strategies to help students to understand and achieve higher grades in their assessments.

As a teacher, I was aware that my students had difficulty in comprehending abstract concepts such as cells, atoms and others, which could not be visualised. This necessitates finding ways and means of making the abstract concepts easier to understand; using analogies to present complex concepts could be one of them. The Akron Global Polymer Academy (2001) is of the opinion that that the research on using analogies lacked quantitative data to prove the efficacy of the previous studies. Such an observation demands the inclusion of an appropriate instrument to collect concrete data in future analogy studies, which would adequately support and establish the conclusion. The course work at Curtin introduced the Two Tier Diagnostic Instruments (Treagust, 1985), which could be effectively used to improve teaching, learning and retention (Treagust, 2006). The use of this type of diagnostic instrument seemed ideal to diagnose the effectiveness of teaching with analogies to simplify complex scientific concepts and identify alternative conceptions. In 2002, Year 8 was tested for their understanding of reproduction in plants and animals with the two-tier diagnostic instruments. In 2003, after the completion of plant physiology in Year 11 biology class, the two-tier diagnostic instruments developed by Haslam and Treagust (1987) was trialled to test the students' misconceptions on photosynthesis and respiration. This was followed by a pilot study on the understanding of protein synthesis after presenting an analogy using the FAR Guide in Year 12 biology class. The outcome was formally reported in the Annual Report of 2004. All these attempts helped to get familiar with the technique of two-tier testing.

1.5 Context of Australian Science Education

The ACER (2007) reported that the TIMSS (2007) provided the results of the Year 4 students' performance in science and indicated that the relative position of Australia remained unchanged since the first administration of the TIMSS in 1995. With regard to Year 8 students' performance in science, the ACER further reported that the score declined by 12 score points since 2003. In terms of cognitive domains, Australian Year 8 students' achievement in the 'knowing' domain was an area of relative weakness, while the 'reasoning' domain was an area of relatively stronger performance. There has been plenty of speculation in the media ever since regarding the performance of Australian children in Mathematics and Science. It is a concern that the current teaching approaches and assessment procedures fail to provide an effective learning opportunities to students. It has been inferred from the above finding that the knowledge domain is weak and therefore, even if the child has the ability to reason out facts, the lack of fundamental content knowledge limits the child's achievement. This necessitates a radical reform in teaching and assessment in Australia.

1.6 Two-Tier Diagnostic Testing

Assessment is an integral part of instruction, which if appropriately designed, ensures that the teacher and students become aware of whether they are on the right track to achieve their 'programmed' goals or not. To achieve this, a teacher needs to find out the students' pre-constructed knowledge before introducing a concept so that the planning and teaching are in accordance with the findings, in order to facilitate deep understanding, long term retention and higher order thinking. The two-tier diagnostic instrument by Treagust (1985) is specifically designed to diagnose student-understanding of a concept on a justified basis quite reliably and validly and to identify students' alternative conceptions. This instrument, if appropriately constructed, with the chosen cohort's preconceptions in mind, has tremendous potential to guide the teacher to plan effective teaching methods and consequently, high student-achievement.

The two-tier diagnostic instrument has two sets of multiple choice items, generally with two to four choices. The first tier relates to the propositional content knowledge and the second tier consists of a set of reasons, which justifies the basis for the students' choice in the first tier. The items for the 'answers' are taken from the content knowledge and the items for the 'reason' are decided mostly on the known students' alternative conceptions. To make the assessment more valid and reliable, the students are also offered opportunities to express their own free response explanations both for the knowledge and reason.

A two-tier diagnostic instrument can be a valuable pre or post teaching tool. If used prior to teaching, it helps a teacher to find the pre-constructed knowledge of the students on the topic and enables the teacher to plan the lesson appropriately and if used as a post-teaching tool, this Instrument can help to find the effectiveness of the offered lesson. The two-tier test might also give clues to the teacher to plan the remedial work, which can address the alternate conceptions. Thus, this convenient, pencil and paper, easy-to-administer test can be a pre and/or post-teaching tool to collect data, which could be used to develop high quality teaching strategies for the deep understanding of scientific concepts. In this research study, two-tier diagnostic instruments, adapted versions of the instrument designed by Treagust (1985), were administered as pre and posttest tools before and after the intervention, which helped to find out the understanding of the concept and alternative conceptions of the students. The questions were structured to test the students' comprehensive understanding of the concept without omitting any of the basic details so that the results would indicate the effectiveness of the intervention.

After deciding on the diagnostic tool, the search for an appropriate technique to present the complex scientific concepts began. Teaching experiences in the past suggested that teaching with analogies could be one of those strategies to make students understand the abstract concepts in science. It was also felt that the frequent use of analogy in science studies might enable students to practise the skills needed to achieve effective inductive transfer. It was envisaged that this practice might enhance their ability to focus, recognise and apply the stored knowledge to different related new situations in the future. This demanded extensive research on teaching with analogies, which brought up the idea of using the FAR Guide to present analogies to explain the abstract scientific concepts to the students. Considering all the benefits, a pilot study was launched in a senior biology class. This initial attempt at the end of 2004 was to incorporate an analogy of a toy helicopter factory to enable the students to understand the process of protein synthesis in cells. It was successful and the students grasped the analog-target relationship and the underlying concept without much difficulty. The diagnostic instrument prepared to test the students was based on the questioning technique stipulated by Treagust (1985). The results were encouraging and this prompted to investigate the benefit of teaching with analogies further, using the same method of testing to collect quantitative data for analysis. This initiated the current study, 'An investigation into the effectiveness of using the FAR Guide to present analogies in teaching and learning scientific concepts'.

1.7 Significance

Cognition is the term used to indicate the deep understanding of a concept. Cognition enables a learner to relate and recall an appropriate concept from one's past experiences due to its underlying significance, while seeking a solution for a present problem. McNeil (2009) quotes a number of cognitive scientists, who seem to think that learners create mental models of visual images in their minds, which are connected or networked to the information that they have acquired as learning experiences. This degree of ability depends on the extent of information that they had accumulated. Deep understanding enhances a student's ability to transfer and use the information in a new context and in a variety of ways. Often, it has been observed that students lack the ability to apply what they had learnt to situations outside the school. This observation shows that the transfer is minimal as a result of limited understanding and inadequate accumulation of information. Teachers need to pay particular attention to enhance students' ability to make connections in new areas based on their existing knowledge. Effective transfer is a skill, which has to be taught and reinforced with repeated practice. Researchers interested in social practice often define transfer as increased participation (Lave & Wenger, 1991); ecological psychology perspectives define transfer as the detection of invariance across different situations (Young & McNeese, 1995). Furthermore, transfer can only 'occur when there is a confluence of an individual's goals and objectives, their acquired abilities to act, and a set of affordances for action' (Young et al., 1997, p.147). Learning must involve more than the transmission of knowledge but must instead encourage the expression of effectivities and the development of attention and intention (Young, 2004).

Students should be given opportunities to develop their cognitive skills through rich contexts, 'which reflect real life learning processes' (Lave & Wenger, 1991). Situated cognition postulates that knowing is inseparable from doing (Brown, Collins, & Duguid, 1989) by arguing that all knowledge is situated in activity. No doubt, teaching for deep understanding and inculcating skills in students to employ what was learnt will demand a lot of the teachers' time and intellect. This will also warrant that the teacher effectively uses a number of explanatory tools to make the information comprehensible and holistic.

It is generally recognized that analogies can facilitate the generation of meaning through a constructivist pathway (Duit, 1991a). As explanatory tools, analogies are particularly common in every day speech and in the science classroom because of their potential to compare one object or situation to another efficiently and, in the process, transfer either details or relational information or both (Curtis & Reigeluth, 1984). Many science concepts and standard techniques can be difficult for students to comprehend. The scientific concepts, if unfamiliar to students in real world situations and/or unperceivable by their senses, are likely to leave large gaps in their understanding. A topic such as how cells function to keep us alive is a highly complex concept, quite baffling to young minds. There were many occasions where students switched over to considering an organelle as an organ within the same context, since they were not able to accept that an organelle, which measures in microns could effectively carry out such sophisticated and complex functions. The same is the mystery of atoms and how they bond with other atoms to make molecules and compounds. Crossing over of chromosomes during meiotic cell division is another abstract concept, which requires repeated explanation and clarification, without which a firm basis to teach, learn and understand genetics cannot be laid.

The students' reflective comments gave the awareness that the explanation with labelled diagrams on the board did help them in understanding the abstract concepts to a certain extent, but the introduction of these concepts with an analogy took them to a higher level of understanding and eliminated alternative conceptions to a large extent; needless to say that the presentation should clearly show the analog–target relationship, and if there are any unshared attributes between them, those attributes should be elucidated with out much delay. Downing (1999) recommends the use of analogies in teaching by quoting constructivist theory:

> In fact, several learning theorists include analogy formation as central tenets. Since analogies are a search between what is already known and what is trying to be learned, they are natural vehicles for constructivist learning to occur-keep on using them. However, there is an abundance of empirical evidence that analogy use often fails because students a) do not understand the analogy properly and b) are not able to draw the analogies intended.

Pitmann (1999) is of the opinion that using student analogies is a good way to determine misconceptions and determining 'whether the student understands the 'why' and 'how' of a concept, which of course is the goal of science education'. Using analogies to teach scientific concepts can be successful, as long as the teacher is aware of the intrinsic and extrinsic details of the concept, and selects the most suitable analogy, which has maximum shared and minimum unshared attributes with the target. It is also vital to structure the teaching method in a systematic and unambiguous manner to make this correlation explicit to the learner. If it is proved that analogies have the ability to enhance student understanding, incorporating analogies as a component in daily teaching would prove to be a constructive teaching strategy. As the students develop cognitively and gain knowledge, they will be able to adopt more sophisticated models at higher cognitive levels without the teacher's assistance. Downing (1999), who reviewed Pittman (1999) on her research findings on analogies, quotes Constructivist theory again and comments, 'meaningfulness depends on the learner's success in finding or creating connections between new information and pre-existing knowledge. One way by which these connections are made is through the use of analogies'

Research by Treagust, Harrison and Venville (1996) has shown that when a competent teacher presents analogies systematically, the resultant student understanding is compatible with the teachers' expectations. Student-world analogies could be effective in simplifying a complex scientific concept, if appropriately and systematically delivered. Short analogies, stories, and/or models could serve as guiding lights for students to visualize science concepts and techniques. Science lessons are full of abstract or challenging concepts that are easier to understand if an analogy is used to illustrate the points. Effective analogies motivate students, clarify students' thinking, help students to overcome misconceptions and give ways to visualize abstract concepts. When they are used appropriately, analogies can also promote students' meaningful learning and conceptual growth (Orgill & Thomas, 2007).

> A learner-centred approach to learning and teaching considers learning as the active construction of meaning, and teaching as the act of guiding and facilitating learning. This approach sees knowledge as being ever-changing and built on prior experience. In the science key learning area, a learner-centred approach provides opportunities for students to practise critical and creative thinking, problem solving and decision making. These involve the use of skills and processes such as recall, application, analysis, synthesis, prediction and evaluation, all of which contribute to the development and enhancement of conceptual understandings (Queensland Syllabus, 2002).

This research study is significant since it adopted a learner-centred approach and endeavoured to find out whether incorporating analogies would help to bring about a better understanding of complex concepts, which students generally find incomprehensible. Today's students, surrounded by digital technology since infancy, are fundamentally different from previous generations (McHale, 2005) and are no longer the people our educational system was designed to teach (Prensky, 2001). Taking this view into consideration and to gain maximum attention and involvement from the students, the analogies were designed and presented using multimedia tools. Further, since it is critical that the analogies are structured and presented clearly and systematically to students to facilitate deep understanding of concepts, the FAR Guide, an established teaching strategy, was adopted to implement the course of action.

The significance of the study is further enhanced due to seeking evidence for reduced alternative conceptions after the presentation of the analogies. The study also speculated whether the analogies would contribute to changing the students’ perception of the concept as a whole with improved understanding; thus paving the right path for future construction and advancement in science study. The two-tier diagnostic tests were administered to find the outcome prior to and after presenting the analogies. The questions were framed in such a manner that there would be sufficient evidence to reveal improved understanding and higher order thinking skills after the presentation of the analogies. It is needless to say that gaining a better understanding in incorporating analogies to teach science is significant in the planning and presentation of science concepts. It was hoped that the resulting knowledge would prove to be valuable in the field of science education.

At the Science for the Twenty First Century UNESCO conference held in July 1999, a new commitment was made with a declaration on science and the use of scientific knowledge. The preamble consisted of 46 points, listed under four subheadings such as: 'Science for knowledge and knowledge for progress, Science for peace, Science for development and Science in society and Science for society'. These brought out the significance of acquiring scientific knowledge by all who 'live on the same planet and are part of the biosphere' and this declaration justifies why effective science education should be a priority for all. If effective teaching strategies are designed and established to make science study enjoyable and the strategies are shared with the global teaching community, it is likely that many of our students would be enticed to choose science and would actively involve themselves with sustained interest in classes. Behaviour problems may decrease resulting in improved outcomes. Learning science may become universal and not just for the 'elite'. Science will be looked at as a guiding light to know, understand, apply and appreciate what life has to offer based on scientific principles. Such an outcome could lead to a better quality of life for all. Imagine a world where every one gives importance to saving the environment, shun nuclear arsenals, conserve natural resources, prevent the spread of diseases, eat healthy food and choose to carry out a million other things, just because they have learnt and know how science works in one's life. There is no doubt that learning and in-depth understanding of scientific concepts will improve the quality of life for every one on this planet. In order to make this possible, research studies have to be conducted to determine various ways of presenting the essential scientific concepts including the complex ones in a simple, comprehensible manner so that our young learners would consider science study as a fascinating and valuable adventure from the time they enter primary school. This in turn, will help to lay a stronger foundation for further construction and the students are likely to choose science at higher levels willingly and consequently, enjoy success in their scientific studies and careers.

1.8 Methodology

Initially, it was decided to present 5 different kinds of analogies to find out which one would prove to be more effective than the other in enhancing student-understanding, higher order thinking and removing alternate conceptions. The reason to include different year levels in the study was due to the eagerness to find out whether the younger or older students would respond to analogies better. Moreover, the analogies had to be presented to the students in the allocated classes, where the teacher-researcher taught science. It may be misleading if a common methodology is presented for all the analogies together. Each chapter contains a detailed account of the individual method adopted to prepare the students for the pretest and the procedure chosen to present the concept incorporating the analogy, followed by the posttest to collect data for the analysis. The teaching strategies, adoption of the FAR Guide, administration of the two-tier diagnostic tests, formal and informal discussions, observation of student behaviour and application of research related components were kept constant to a large degree in all the year levels to ensure validity and reliability of the collected data. The introduced concept was new to all the students.

The research undertaken may be categorized as action research. It was cyclic, allowing similar steps to occur in a similar sequence. The specification in the FAR Guide was strictly adhered to in all the presentations, which allowed repeated cyclic processes to occur. The study was also participative since the students were active participants in learning and peer teaching while contributing data to make conclusions. The research was reflective, both on the part of the teacher and students, allowing opportunities to reflect critically on the intervention by adding valuable data to the study. The FAR Guide included in the chapters for all the analogies contains the 'Reflection' and observation written briefly. As indicated in the students' reflective comments, the analogs resembled the targets closely and did not raise any unwarranted issues. The response from the students was consistently positive. The observation and written answers in the examination indicated that the students needed more help on the

Quantum model. This post-reflection led to the addition of laws and rules in a comical manner to the presented analogy and the presentation was viewed again.

The research involved both action and research and was responsive and flexible. The flexibility and responsiveness provided a check on the adequacy of data needed to make conclusions. Though the research method was carefully planned and executed without any assurance to prove or disprove the claims that analogies benefited students in understanding complex science concepts, the data collected confirmed that the analogies did help in understanding the complex concepts in science, reduced misconceptions and improved higher order thinking skills. This was not realized until the data was compiled, analysed and conclusions were made. The flow chart on the following page shows the components of the research undertaken and method adopted for the study.

1.9 **Action Research**

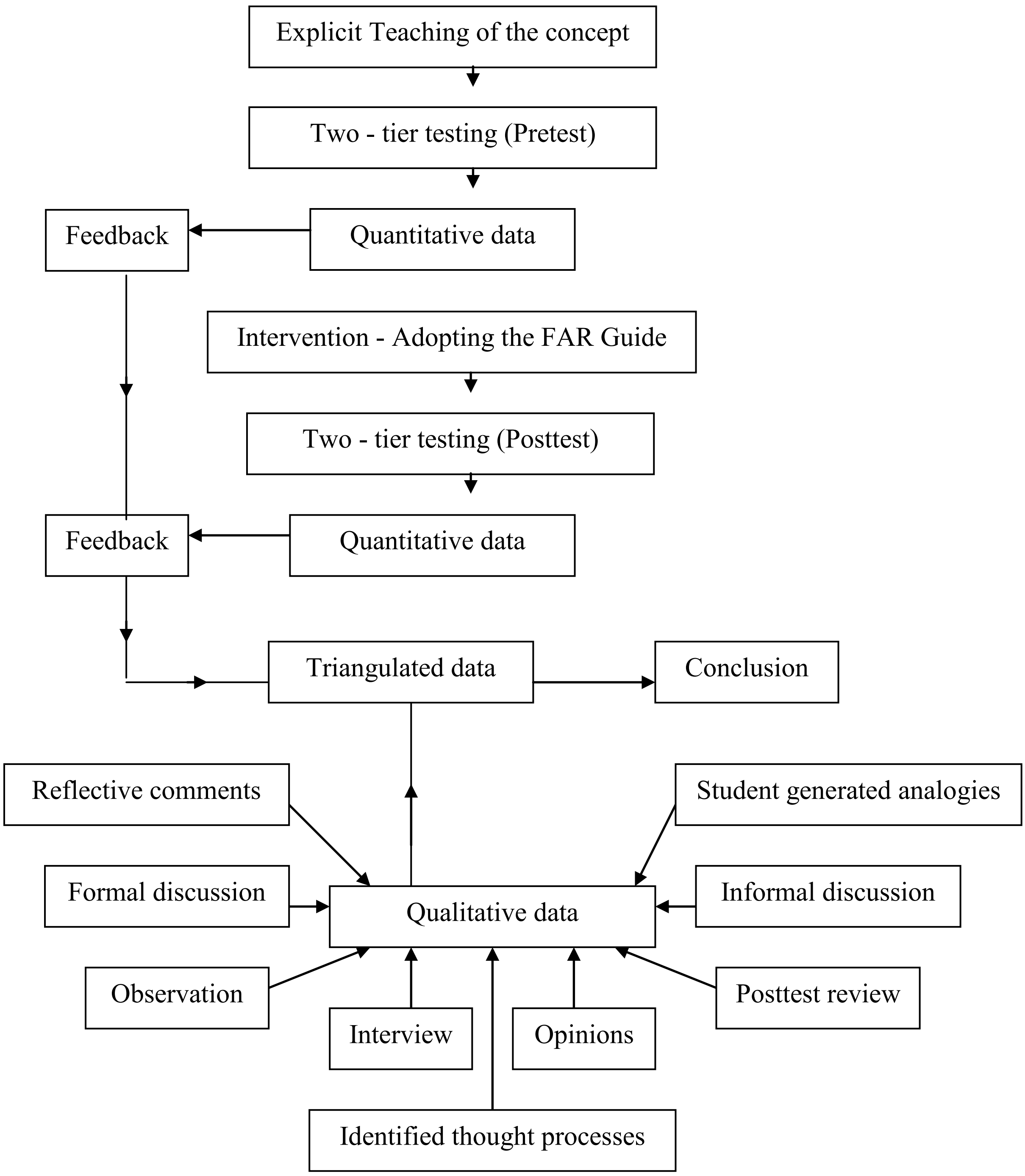


Figure 1.1 **Action research - A Flow Chart showing the Components**

1.10 Higher Order Thinking

Curriculum Implementation Unit, Education Queensland (2002) ascribes the following as requirements for 'higher order thinking' in learners:

> Higher order thinking requires students to manipulate information and ideas in that transform their meaning and implications. This transformation occurs when students combine facts and ideas in order to synthesise generalise, explain, hypothesise or arrive at some conclusion or interpretation. Manipulating information and ideas through these processes allow the students to solve problems and discover new (for them) meanings and understandings.

> A dominant component of the current reform in science education is a purposeful effort to develop students' higher-order cognitive skills (HOCS) of question-asking, critical thinking (CT), system thinking, decision making and problem solving (PS), as opposed to 'traditional' algorithmic-based lower-order cognitive skills (LOCS) (Zoller, 1993 in Zoller & Pushkin 1997).

Considering the importance of including strategies to inculcate higher order cognitive skills in students, it was decided to test whether the analogies contributed to enhancing student's higher order thinking skills. Of the fifty two-tier multiple choice questions framed for the five analogies, twelve of them (24%) were included at random and these required higher order thinking to answer correctly. The data was collected from the pre and posttests for analysis to make a conclusion and the results are added in the concluding chapter (Ch 8). Moreover, the questions included in 'probing the thinking process in students' gave significant indication of higher order thinking in students after the analogy was incorporated in teaching the concept.

1. 11 Pre-service teachers involved in the study

Two pre-service teachers participated in the study:
Ross Vidler: Ross came to Yeronga State High School for his final practicum from Queensland University of Technology. He was studying a double degree in education at QUT and was almost at the end of his studies when he came for training. He was under my supervision for his 6 weeks' teaching practice in junior science.

Ruth Mikulich: Ruth came from Canada to the University of Queensland to complete her final year in Education and practice teaching. Ruth was supervised during her 6 weeks' teaching practice in secondary biology. She was also at the end of her teaching degree and was appointed at the same school as the science teacher in the following year, where she is still continuing.

1.12 Development of the thesis

The teacher-researcher was moved me to 5 different State schools from January 2000 to December 2003 due to student withdrawals. The prevailing conditions in those schools were not favourable for systematic research; hence engaged in action research given below:

Preliminary studies 1 (to get familiar with the two-tier diagnostic instrument) - 2002
(Year 8 Science) What do you know about reproduction in plants and animals?

Preliminary studies 2 (to get familiar with the two-tier diagnostic instrument and the FAR Guide) - 2003
(Year 11 Biology) 1. What do you know about photosynthesis and respiration?
2. What do you know about cells in plants and animals?

Joined Yeronga State High School in 2004. After a year of familiarisation, found the school favourable to conduct research

***Pilot Study (Trial using the FAR Guide to present the analogy and two-tier testing)* 2004** (Year 12 Biology)What do you know about protein synthesis in cells?

Systematic research started from 2005

***Quantitative and qualitative data collection – First batch* 2005**
Year 8 (Science) What do you know about atoms and molecules?
Year 8 (Science) What do you know about cells in plants and animals?
Year 12 (Biology) What do you know about crossing over during cell division?
Year 11 (Chemistry) What do you know about electrons in atoms?
Year 12 (Biology) What do you know about protein synthesis in living organisms?

Quantitative and qualitative data collection – Second batch 2006
Year 8 (Science) What do you know about cells in plants and animals?
Year 12 (Biology) What do you know about crossing over during cell division?
Year 11 (Chemistry) What do you know about electrons in atoms?
Year 12 (Biology) Thesis preparation What do you know about protein synthesis in living organisms?

Quantitative and qualitative data collection – Second batch 2007
Year 8 (Science) What do you know about atoms and molecules?

Addition to qualitative data - 2007 - 2008
Atoms – Questions to probe the thinking process
Informal discussion to collect qualitative data
An opinion survey at the end of the year followed by discussion on the analogy game

Compiling and analysing data &

Thesis preparation 2008 - 2010

Figure 1.2 **Flow chart showing how the thesis was developed**

1.13 Summary of the chapter

This chapter has included:

A brief account of an incident in the classroom, which initiated the interest in using analogies to simplify and teach complex scientific concepts and the resulted eagerness to find out more about teaching with analogies, which led to taking up this research

The choice of using the two tier diagnostic instrument to collect pre and posttest quantitative data, its significance and relevance in finding out the effectiveness of the intervention

The decision to choose an effective and systematic approach to teach science using analogies, the choice of the FAR Guide and the significance and advantage of adopting this procedure

The statement of the purpose of the study and objectives

The research design, which gives the details of the action research undertaken in the past: finding the depth of scientific knowledge and students' ability to apply the knowledge in real life situations, multiple intelligences in students, ability to think scientifically, using concept maps in science learning, motivation to learn science and how all these paved the way to take up this research

The reasons for justifying the study as an action research involving the presentation of different kinds of analogies as the intervention and gathering quantitative and qualitative data in different ways, which makes it difficult to write a common methodology

Two flow charts to show the components of the action research and timeline on the development of the thesis

The reason for including analogies to find out whether they had the potential to promote higher order thinking in students and

A brief reference to the pre-service teachers who participated in the study.

Chapter 2

Review of Related Literature

2.0 Introduction

This study was undertaken to find out whether a systematically planned and presented analogy using the FAR Guide has the capacity to enhance student understanding, minimise alternative frameworks and improve higher order thinking. The sample consisted of 154 students from a state high school in Queensland, which caters for learners coming from 50 different ethnic groups settled in Australia. Five different analogies were presented to students in grades 8, 11 and 12, aged 12-18 years, as a component of their science, chemistry and biology lessons respectively. This chapter begins with a brief reference to teacher research framework (section 2.1) and continues with the review of a few learning theories which have relevance to the study undertaken (section 2.2). The first part (section 2.3) deals with constructivism and constructive approaches, the second part (section 2.4) gives additional cognitive theories compatible with learning with analogies and the final part deals with analogy related theories in detail. The modus operandi of the FAR Guide has been elaborated in relation to teaching and learning of science concepts. Each theory concludes with its relevance to teaching with analogies and the chapter concludes with a summary of the literature review.

2.1 Teacher Research Framework

Abell and Lederman (2007) quote Ball (2000) to define teacher research as 'deliberate fusing of the work of teaching and the work of inquiry'. The research has a goal, an aspiration to understand an educational practice, laying emphasis on changing the practice if the change were to assure better rewards. The emphasis on change and improvement of practice could involve any one or more different aspects of teaching and learning. In this study the aspiration was to investigate whether incorporating analogies to teach complex concepts in science has any impact on student-understanding. The strategy in this study demanded the combined effort put forth by the teacher and learners and yielded relevant quantitative and qualitative data for triangulation. 'Teacher-researchers raise questions about what they think and observe about their teaching and their students' learning. They collect student work in order to evaluate performance, but they also see student work as data to analyse in order to examine the teaching and learning that produced it' (MacLean & Mohr, 1999). The inductive and deductive research methods have their own merits and triangulation of both quantitative and qualitative data is the only way to make the conclusions credible Cohen, Manion & Morrison (2000, p.112).

2.2 Learning Theories

The following learning theories are included and discussed due their relevance to the study: Constructivism and Constructivist approaches to teaching such as the Driver's Constructivist Teaching Sequence, Concept Substitution, Contrastive Teaching, Conceptual Change Model, Concept Attainment and Cognitive Development Theory. A few modern theories such as the Learning Cycle, Generative Learning Model, Visual Learning and Neuroplastic Learning are added to the above list. Further, a brief account of the use of analogies in human history followed by a few theories relating to teaching with analogies such as the Bridging Analogies Approach, TWA Model and the FAR Guide have been included and elaborated. The last theory, Brain Compatible Learning Theory appraises the use of analogies in teaching scientific concepts and supports this approach with evidence provided by neuroscientists based on neuroscientific studies using the latest fMRI techniques.

2.3 Constructivism and Constructivist Approaches

Constructivist theory predicts that students are more likely to find a science topic interesting and worth studying if they see it as relevant and connected to familiar things. Teaching with analogies works because analogies try to relate the unfamiliar to the familiar (Harrison & Coll, 2008). Constructivism refers to the idea that knowledge is constructed, both individually and socially, by the learner. Construction cannot occur without the associated experience and thinking. Analogies associate a student's past experience, a familiar analog, with a new concept and lay the foundation to construct further knowledge. Constructivism is a dynamic and interactive model of how humans learn (Bybee, 1997). Similarly, teaching with analogy demands the active participation of the teacher and students, as specified in the FAR Guide, starting from focus through action to reflection. It is totally interactive and dynamic and draws out all that a student and teacher can offer during the analog-target mapping and lays it on the table for every one to partake for their own benefits. More learning comes from sharing the experiences of the peers than from just the contribution of the teacher. The students have more opportunities to construct their own knowledge while learning with analogies than having the concept taught using traditional methods. Constructivist theory states that in such a constructivist classroom, the teacher provides students with experiences that allow them to hypothesize, predict, manipulate objects, pose questions, research, investigate, imagine, and invent. The teacher's role is to facilitate this process. According to Hiebert and Stigler (1999), constructivism views learners as active participants in the creation of their own knowledge. This is due to their interaction with their environment, both real and imaginary, which enables them to interpret the world. Learning often occurs in social contexts, and, therefore, the learner's relationships with other persons serve a vital function in the interpretation process. In learning using analogies, the analogy offers an imagery to connect to the concept, effecting conceptual growth. It was explained earlier that this learning revolves around the contribution from the teacher and peers, and hence occurs in a social context. On the part of the teacher, it is required that all the available information from the student-world is recognised and utilised to design or find an analogy that suits the concept, making sure that the analogy leads the students to higher-levels of cognitive processing and achieve analogical reasoning; thus, learning with analogies qualifies to be a constructivist strategy.

2.3.1 Driver's Constructivist Teaching Sequence

The model proposed by Driver (Driver & Oldham, 1986) is the basis for many studies on students' alternative frameworks. The teacher elicits students' ideas prior to presenting the scientific ideas and negotiates with the students as a facilitator. The students work to identify and develop their own theories. The theories are then compared and evaluated by the members of the class. The teacher introduces the activities, guides the students towards the accepted scientific view and gives ample opportunities to apply the accepted theory. This approach has wide acceptance and has proven effective. However, there is a possibility that a few students may not see the differences between their views and the views delivered by the teacher. This requires further planning and effective follow up. Fundamentally, learning has to do with constructing knowledge to make what is unfamiliar, familiar. In this case, the analogy is one of the most often used methods which has the specific characteristics to relate familiar visual information stimulus to depict the otherwise abstract domain of learning (Black & Solomon 1978, Duit, 1991; Jonassen, 1994 (in Shu-Ling, 1998)). The constructivist teaching sequence if scrutinised carefully shows the specified steps in the FAR Guide, which is recommended as a systematic approach to present analogies to teach complex concepts. The 'Focus' stage involves eliciting students' preconceived ideas on the concept, which gives the guidance to plan and present the analogy linking with the concept, followed by the presentation and analog-target mapping, which is the 'Action' stage and the final 'Reflection' helps to find the effectiveness of the analogy, both by the teacher and students; in a way, similar to constructivist teaching sequence. The teacher's effort to encourage the students to generate their own analogies is comparable to students developing their own theories as proposed in constructivist teaching sequence.

2.3.2 Concept Substitution

Grayson (2004) explains a phenomenon viz. concept substitution, which promotes conceptual change in situations, where the student has a correct understanding of the process associated with a misnomer such as a technical term in physics. Associating the correct term with the corresponding process with visual aids, demonstrations, experiments and explanations bring about concept substitution. In this way, the correct term is reinforced in the memory for a long period. An analogy could serve the same purpose. An appropriate analogy will act as an effective temporary substitute to remove alternative conceptions till the learner develops the correct perception of the target, resulting in proper understanding and long term retention. Moreover, if teaching with analogy is coupled with an effective teaching technique to acquire an inherent understanding of the related scientific vocabulary, the learning would be complete. This would enable effective construction at a higher level with minimum stress, since the foundation for understanding the new learning has been already laid. Teaching Greek and Latin (or other) origin of words is an effective way of achieving this purpose. It would also be pleasing to a science teacher to listen to students using scientific terms fluently in their conversation and expression instead of substituting the technical terms with 'things' and 'thingy'.

2.3.3 Contrastive Teaching

Contrastive teaching, published by Schecker and Niedderer (1982) is more appropriate for the upper secondary level and university students. This strategy consists of six stages viz. preparation, initiation, performance, discussion of findings, comparison with scientific theory and reflection. During the preparation, the teacher presents the concept as in traditional teaching and demonstrates experiments. The initiation starts with an open minded problem posed by the teacher. Different apparatuses are made available for open ended experiments. The presentation of the problem depends on the expertise and creativity of the teacher to maximise student participation. During performance, the students hypothesise, design experiments, test and formulate their results. The teacher is a facilitator, counsellor and guide with no direct involvement in students' activities. During discussion and findings, the teacher puts the ideas on the board in their own words. The students compare their results and arrive at a common conclusion. The teacher notes down the inconsistencies and misinterpretation and initiates a further dialogue or experiment, depending on the requirement. The teacher presents the scientific explanation as an alternative view and compares it with the students' view during the next stage. The students perceive the commonalties and the differences similar to analog-target mapping. The teacher then correlates the scientific view with every day life activities and events and explains the advantages. During reflection, the students think about the problem, finding and solving issues. The students appreciate the findings from the philosophy of science, which can be applied to many facets of every day life to make life more pleasant and easy. The number of stages in teaching a concept/topic could be reduced to suit the situation. Contrastive teaching is a learner-directed approach, where the teacher creates conditions for active engagement in learning and reasoning. The teacher needs to be aware of the difference between the students' intuitive views acquired from every day experience on the concept.

This runs parallel to the procedure adopted in implementing the FAR Guide to present analogies. The different phases in contrastive teaching align with the Focus, Action and Reflection stages of the FAR Guide; needless to say that the analog-target mapping which brings out the similarities and dissimilarities in detail is nothing but the comparison adopted in contrastive teaching. Learning with analogies is even better since the analog offer help to clarify the unfamiliar with the familiar. Moreover, the less number of steps involved in the FAR guide enables easy implementation. When students are encouraged to generate their own analogies repeatedly and share with the others in class, patterning gets established in the brain to create and develop more sophisticated mental models of the concept, thus attaining metacognitive awareness.

2.3.4 Conceptual Change Model

The classical Conceptual Change Model, developed by Posner, Strike, Hewson and Gertzog (1982) describes learning as a process in which a person changes his or her conceptions by accommodating new conceptions, thereby attaining conceptual change. This change could occur due to restructuring or replacing the existing conceptions. This is common to the constructivist teaching strategies and belief that students create their own knowledge. Students have initial ideas to explain a phenomenon they observe. When expected events occur, students assimilate them into their pre-existing knowledge networks, but when unexpected events occur, students are expected to accommodate the discrepancy by restructuring their knowledge network. Assimilation is known as conceptual growth, while accommodation is called conceptual change. Conceptual change occurs at concurrent stages, when the student identifies the view presented by the teacher intelligible, meaningful, plausible and harmonious with his preconceptions for easy reconciliation. This could eventuate into using the conception to evolve new ideas or engaging in metaconceptual activities. The greater the extent of application, the higher is its status. The teacher serves as a facilitator, setting ground rules in negotiation with the students.. The students comprehend the goals of learning, learn to accept and respect others' views and eventually accept responsibility for their own learning. There is freedom to express one's views and critique, willingness to negotiate and compromise and show mutual respect for each other's views despite disagreement. The commendatory end result would be that the students are in agreement with the teacher's view.

When a teacher uses an analogy as a teaching tool, the expectation is that these analogies would bring out a favourable conceptual change in students. The students are given opportunities to express, share, change, renew, modify or refine their ideas of the concept to something right and proper. The analogies lead to this change by offering support and guidance to reconstruct their understandings. During this process, the students accept, respect and accommodate others' views as it is often witnessed in analog-target mapping. Moreover, due to the familiarity of what is being taught, there will be improved student participation since the analogy helps to grasp the intangible. The analogies have the potential to simplify a complex scientific concept by offering a familiar ground for the learner to understand an unfamiliar situation, thus effecting conceptual change, which aligns with the teacher's view.

2.3.5 Concept Attainment

Concept attainment is essentially the expected outcome a student achieves and this has been elaborated by Bruner, Goodnow and Austin (1967). Teaching with analogies envisages that all students develop mental models of the concept assisted by the analogy given to them. Analogies are expected to clarify students' ideas and offer 'stepping stones' till they are made concrete in order to attain metacognitive awareness. Listing positives and negatives in the concept attainment strategy is similar to analog target mapping. The advantages seem to be similar in helping students to establish connections between what students already know and what they would be learning. The students also learn to sort out relevant information for understanding and problem solving, thus achieve concept attainment.

2.3.6 Cognitive Development Theory

Chapman (1988) in his review of Piaget (1972) comments that Piaget's research demonstrated that children's thinking is qualitatively different from adults and he concluded that children need to construct or reconstruct knowledge in order to learn and that they should be given sufficient opportunities to interact with the physical world and with their peers. The curriculum should be designed to contribute to students' logical and conceptual growth and the teacher should offer and guide the learner with rich experiences and interactions with the real world so that the students will establish concrete cognitive structures. Cognitive theory proposes that activities which require the learner to relate new information to existing schema can impact on and facilitate learning (Ausubel, 1960; Gagne, Briggs, & Wager, 1988; Rumelhart & Norman, 1981 in Shu-Ling (1998). Knapp (2000) defines thinking in the words of Beyer (1987) 'as involving perception, prior experience, conscious manipulation, incubation, and intuition'. When analogies are introduced, students exercise higher order thinking in their search for meaning and this involves all the mental processes that make sense out of experience. Analogies have the ability to draw and hold students' attention due to their familiarity i.e. if taken from the students' world. When this is achieved, the next step in the process would be conceptual growth leading to concept development. These mental processes take place at different cognitive levels in different individuals because of their individual differences; nevertheless, it is understood that analogies enable better understanding and reduce alternative conceptions as a result of cognitive development. The analogies seem to link the concept to students' prior knowledge and offer specific mental strategies that evoke understanding in the learner, thus helping to attain the conceptual change.

2.3.7 The Learning Cycle Approach

Zollman and Robello (1998) present a detailed account of the history of the development of the Learning Cycle Model by Karplus and Thier (1967) for SCIS, the Science Curriculum Improvement Study.

This approach reflects the theoretical framework of Bruner that learning is an active process in which learners construct new ideas or concepts based upon their current and past knowledge allowing the individual to go beyond the instructional context. The learning cycle approach, which originates from a Piagetian perspective, has been proposed as a means to enhance conceptual change (Stepans, Dyche & Beiswenger, 1988 in Treagust, D.F., Duit, R. & Fraser, B. (1996)). There are three phases in this inquiry-based teaching strategy such as the Exploration phase, in which the students are given first-hand experiences associated with the concept, (corresponds with the tracing of the analog-target relationship), Concept introduction phase, which allows students to construct science ideas through interaction with teachers, and peers (analog-target mapping recorded on the board, followed by discussion), and finally, Concept Application phase, when the students are facilitated to apply the concept to new situations (analogical reasoning and discussion of student generated analogies).

Currently there are many modified versions of the original Learning Cycle model. Barnum (1989) describes Lawson's (1988) identification of three different types of learning cycle lessons: such as descriptive, empirical-inductive (abductive) and hypothetical-deductive. All of them have retained the essence of the original Learning Cycle, but the number of phases differs. A popular version of the Learning Cycle is the 5 E Model proposed by Bybee (1997) consisting of: Engage, Explore, Explain, Elaborate and Evaluate. The teacher finds out the prior knowledge of learners, investigates the concept and explains the outcome, elaborates for better understanding and offers an opportunity for self reflection to the students. Analogies can be useful instructional tools in each phase of the 5 E instructional model (Orgill & Thomas, 2007). The FAR Guide could be easily related to the Learning Cycle Model. The Action phase is when the teacher *engages* the students by introducing a familiar analog from the students' world by asking open-ended questions and eliciting answers from them. Once the teacher feels that the stage is set for the Focus phase, students are led to *explore* the intrinsic and extrinsic details of the analog and relate them to the features of the target. The teacher and students map the similarities and dissimilarities together and record them on the board. The teacher may have to *explain* and facilitate correct understanding and remove alternate conceptions. There may be opportunities to *elaborate* the concept referring to other real world situations and in the end, during the Reflection phase, the teacher *evaluates* the understanding of the concept and gives feedback. There may be instances where the teacher will have to modify, reorganise, add or delete details based on the finding during reflection or introduce a totally different analogy for better understanding.

2.3.8 The Generative Learning Model

According to Wittrock (1991), 'The generative model is a model of teaching of comprehension and the learning of the types of relations that learners must construct between stored knowledge, memories of experience, and new information for comprehension to occur'. Flick (1996) describes generative learning as 'the active process of saying, "Oh. That's like ..." It's the process of constructing links between new and old knowledge, or a personal understanding how new ideas fit into an individual's web of known concepts', the same as learning with analogies. Wittrock believed that learning would occur when links are generated between the contents of short term memory and long term memory, which is our knowledge base. These connections between the new and old information result in understanding. There could be erasure or modification of the 'old' idea, as determined by the brain. The recent studies on brain activity conducted by neuroscientists using fMRI (Kirchhoff & Buckner, 2006) support this view. The teacher facilitates student-thinking to make connections by engaging them in appropriate mental activities. The analogies in teaching establish links between what is familiar with the unfamiliar, thus engendering conceptual change due to the newly established or re-established links during analog-target mapping.

2.4 Additional Cognitive Theories Compatible with Learning with Analogies

2.4.1 Theory of Brain Plasticity or Neuroplasticity and Learning

Controversial to the belief that as we aged, the neural connections in the brain become fixed, this newly observed phenomenon, neuroplasticity, refers to the brain's ability to change throughout life. The changes associated with learning occur mostly at cellular level, mainly at synapses. When new connections form, the internal structure of the existing synapses can change. Changes can be observed in certain specific areas of the brain associated with the new activity, and if the activity continues for extended periods, an increase in mass or volume results in the corresponding area of the brain. Changes are also seen in the release of neurotransmitters and other related neurochemicals.

Gaser and Schlaug (2006) compared the brains of professional musicians, amateur musicians and non-musicians. They found the volume of the grey matter in the cortex was the greatest in the professional musicians, who practised music at least one hour a day, intermediate in the amateur musicians, who practised whenever there was a need and the least in non-musicians. The associated parts of the brain involved in playing music, such as the motor regions of the superior parietal areas and inferior temporal areas also showed corresponding increase in size. This has been explained in terms of plasticity. Maguire, Woollett and Spiers (2006) published a report on a study conducted at the University College, London, on the brain activity of 18 licensed taxi drivers, who had to navigate according to the request of the clients and 17 bus drivers, who followed a fixed route. They found that the posterior hippocampus region of the taxi drivers was larger than the bus drivers. This region is responsible for acquiring and using complex spatial information in humans and help to navigate efficiently. Price et al (2007, p. 1184) reported that 'the structure of the adult human brain changes when a new cognitive or motor skill is learned. This effect is seen as a change in local grey or white matter density that correlates with behavioral measures'. Draganski and colleagues (2006, p. 6316) confirmed that extensive learning of abstract information can also trigger some plastic changes in the brain. They imaged the brains of two groups of medical students three months before and after their examination using fMRI. The first group studied for the examination and the second, did not. They concluded that, 'Learning induced changes in regions of the parietal cortex as well as in the posterior hippocampus. These regions of the brains are known to be involved in memory retrieval and learning'.

How does neuroplasticity relate to teaching with analogies approach? The AGPA, Akron Global Polymer Academy (2001) gives an account of their research findings in using multiple analogies. It states that 'studies of chemistry and biology instruction show that some students, who are exposed to and who become skilled in the use of multiple analogies, develop a more scientific understanding of particular science concepts than do students who concentrate on one acceptable analogy'. Could this be attributed to the plasticity of the brain? This observation warrants further research to find out conclusively the outcome of using one analogy for one concept and using multiple analogies for the same concept in the light of neuroplasticity. Nevertheless, it gives us the insight that analogies benefit students in enhancing the understanding of a concept; perhaps the mapping exercises and the other associated teaching processes and engaging in analogical reasoning involve and develop the concerned faculties of the brain and increase the efficiency of the learner to attain a favourable conceptual change and the ability to acquire higher levels of cognitive learning in the future.

2.4.2 Visual Learning

Visual images enable students to see the connection in ways that are easy to understand and help reveal relationships and patterns. A visual or pictorial analogy might capture a student's attention better than a verbal presentation of the same. 'Visual analogies' (Duit, 1991a, p.655) facilitate a visualization of the abstract target domain. Many researchers highlighted the power of visual analogies in urging students to form mental images as they studied the material'. Harding and Terrell (2006, p3), after their extensive research on learning styles, concluded that 'research in both educational theory and cognitive psychology tells us that visual learning techniques are among the very best methods for teaching students of all ages how to think and how to learn'.

Visual learning when combined with technology enables students to clarify thoughts, organize and analyze information, think critically and integrate new knowledge by visually seeing how items can be grouped and organized (Harding & Terrell, 2006). When the information is linked to prior knowledge, new concepts are more thoroughly and easily understood. It is also possible that visualization makes processing the information about science more engaging, thus causing the listener to attend more closely to the material (Shapiro, 1985). In an experiment conducted by Nunley (2002), a student was given both auditory and visual stimuli simultaneously. The magneto-encephalography (MEG) scan showed electrical activity in both the sensory regions of the brain, showing that the brain was the receiving information from the eyes and ears. The brain activity, which followed, showed that the brain processed only the visual stimuli, and not the auditory information. Nunley concluded that the subject's brain showed a preference for visual stimuli. Further research by Nunley (2004) revealed that there are learners who show visual, auditory and tactile preferences. She subsequently recommended offering multiple learning experiences to facilitate learning.

Smith, Singh and Greenlee (2000) used fMRI techniques and examined the nature of the changes that occurred in the human visual cortex when an observer attended to a particular location in the visual image. The authors stated that the magnitude of the response to a visual stimulus not only increased when the observer attended to the stimulus, but also attention to a particular location resulted in a widespread suppression of activity levels at all other locations. The finding suggests that 'a key mechanism of attentional modulation may be that spontaneous (baseline) levels of neural activity are adjusted in a position-dependent manner across the entire visual field'.

According to Cadena (2002), many engineering students prefer visual learning and this learning seems to be complemented by audio and to a lesser extent, kinaesthetic and tactile means. Cadena considered that the use of electronic equipments in classrooms can enhance students' visual and audio learning experiences. All these findings were taken into consideration when the analogies were designed for this study, so that they would offer visual, auditory, tactile and kinaesthetic stimuli and multiple learning experiences to the learners. All the analogs were colourful visual representations projected on a large screen for better perception. The analog-target mapping was interactive and the mapping was displayed on the white board as and when the points were raised and agreed upon by the rest of the class. The points were articulated clearly for peer acceptance and understanding, thus offering both visual and auditory stimuli while presenting all the analogies. The atom game analogy offered multiple learning experiences in addition to the above and kinaesthetic stimulus. They had to flip the card, do the calculation to find the number of electrons for the given element and run around to align themselves in the 'orbits' before the other team got organised. The students commented on sharing their understanding of the concept while directing the members of the team to take their positions in the 'orbits' as something positive to reinforce what was learnt. The analogy for crossing over offered tactile experience in addition to visual and auditory stimuli involving cutting and swapping of segments and writing the traits on the strips. It also offered mental and visual stimuli to sort out the maternal and paternal contributions of the genes based on the colour of the strip.

2.4.3 Brain Compatible Learning

With the advancement in technology such as the Functional Magnetic Resonance Imaging (fMRI) technique, neuroscientists are able to observe the activity of the various parts of the human brain during learning. It is mind boggling to read the results of their investigations to understand the underlying neural mechanisms of learning. The investigation conducted by Kirchhoff and Buckner (2006) in the laboratory of Washington University using fMRI may be significant to educators. Kirchhoff and Buckner (2006, p. 264), whose initial aim was to explore individual differences in memory, documented that 'This procedure, (fMRI), allowed exploration of the relationship between individual differences in reported strategy use and individual differences in memory performance and regional brain activity during intentional encoding'. According to them, four strategies were employed by the participants in this study: A visual inspection strategy, in which the participants carefully studied the visual appearance of objects, a verbal elaboration or word-based strategy, in which individuals constructed sentences about the objects to remember them, a mental imagery strategy, in which participants formed interactive mental images of the objects, similar to animated cartoons, and a memory retrieval strategy in which they thought about the meaning of the objects and/or personal memories associated with the objects. According to Kirchhoff, those individuals who used the first two strategies often had better memory performance than those who used them rarely or not at all. Kirchhoff also says that, 'There's a great deal of variability in strategy use when people are free to choose their own learning techniques. We also discovered that individual people use multiple strategies to learn new information'.

Sutton watched the sleeping brains of 15 people using fMRI and gave an account of learning while sleeping. Cromie (Harvard University Gazette, February 08, 1996) quotes:

> During dreaming, he (Sutton) saw waves of activity starting in the brain stem, moving up through areas concerned with emotion and memory, then spreading over the cortex. One theory holds that this excitement involves consolidation of information learned during the day. The process could include discarding what the brain considers junk mail, as well as making new connections between brain cells. Called unsupervised learning, the latter produces novel associations and thoughts. You often hear people say, "It came to me in a dream".

This finding has been considered significant. Chapter 1 narrates an incident about one of my students, who had a dream of the visual image of the brain wrapped in plastic coverings as an after-effect of the analogy presented to her during the day; the incident, which gave the initiative and motivation to embark on analogies for this research. Could it be that in her sleep, during unsupervised learning, her brain cells formed new connections to store the information? In which case, why not, an analogy for every concept?

There are a few parallel studies, which used fMRI to observe the activation of brain during learning. The experiment conducted by Schwartz, Maquet and Frith (2002) is significant to teachers. Based on their research findings, they concluded that repeated experience with a visual stimulus can result in improved perception of the stimulus, resulting in perceptual learning. Would a permanent display of a pictorial analogy during the period when an analogy is taught help in better perception and understanding?

Most of the post-training improvements seem to be sleep-dependent and develop only over several hours. The above researchers further observed that if the subjects are deprived of sleep the first night after training, subsequent improvement was prevented. A few other neuroscientists have also observed that the integration of information takes place over a period of three hours to eight days, resulting in long term retention (Orban et al, 2006). Educational Psychology recommends 'distributed practice', a procedure for learning a skill, in which small units of practice are alternated with rest periods; usually the practice time is less than the rest time. This could be explained in the light of these recent findings that the animal and human brains need time to integrate the essential information for long term retention by sifting through vast amounts of information gathered and deleting what the brain considers as nonessential gibberish.

Caine et al (2008, p.4) in her 12 Brain/Mind Learning Principles in Action states 12 principles; the summary of which essentially is: learning is physiological consisting of conscious and unconscious processes involving both focussed attention and peripheral perception. The Brain/Mind is social and the search for meaning is innate and occurs through patterning, which is affected by emotions. Learning is developmental and the brain/mind processes parts and wholes simultaneously. She recommended two approaches to enhance memory and retention, by assisting students to archive individual facts or skills and making sense of experience.

Caine cautions that complex learning is enhanced by challenge, but learning is inhibited by threat associated with helplessness. Each brain is uniquely organized and therefore a combination of a variety of teaching strategies would bring out the best in students. Would a set of analogies for the same concept be more effective in learning? According to Caine, search for meaning is making sense of one's experiences. In patterning, mind makes use of the acquired and innate patterns such as schematic maps and categories. The 'categories' could be interpreted as learning tools used as powerful stimuli, which we concede as metaphors, analogies and others. The brain considers what has been already experienced as familiar, while readily responding to anything novel, in attempting to discern and understand patterns to create its own expression. Caine believes that 'emotional impact of any lesson or life experience may continue to reverberate long after the specific event that triggers it', thus resulting in long term retention. According to Caines' (2008) 'Two Brain Doctrine', both the hemispheres of the brain are constantly interacting, reduce the information into parts and perceive holistically at the same time. Caines recommend that teaching should cater for natural, global learning relating to real life situations.

Since fMRI studies reveal the exact nature of learning rather than speculating the effect of learning superficially, the educators should give more importance to any kind of teaching, which is brain compatible and achieves perpetual learning. Learning science using analogies could be considered as brain compatible since the students construct new information based on familiar experiences, which is stored in the brain. Repeated analog-target mapping is likely to establish patterning in the brain, which might lead to seeking similar situations as that of an analogy to understand a complex phenomenon. Sometimes in this attempt students might generate their own analogies for better understanding and retention. A basic component of cognitive abilities is a special kind of 'symbolic ability - the ability to pick out patterns, identify recurrences of these patterns despite variations in the elements that compose them, to form concepts that abstract and reify these patterns, and to express these concepts in language. Analogy, in its most general sense is this ability to think about relational patterns' (Gentner, Holyoak & Kokinov, 2001).

2.5 Analogies in Teaching and Learning

Analogy is a cognitive process of transferring information from a particular subject, the source known as 'analog', to another corresponding subject, 'target', accompanied with a description of how they are alike or similar. Analogy has been perceived as 'the core of cognition' and 'lifeblood…of human thinking' (Hofstadter, 2001). Analogy is a powerful relation that makes new information more concrete and easier to imagine (Shapiro (1985). The Roman lawyers used the Greek term, 'analogia' and exercised analogical reasoning. Jewish teachers of the 1st century A.D. made use of comparisons in narrative form to clarify scriptures. In the Bible the 'parable' not only denotes metaphors, analogies, and enigmatic statements, but also short illustrative narratives. Jesus' parables compared observable, natural, or human phenomena to certain abstract, intangible and unrealised Christian doctrines. Greek philosophers such as Plato and Aristotle saw analogy as a shared abstraction (Shelley, 2003). Folklores across the continents used analogy to teach significant, culture-based moral ethics. The Greeks accepted allegories, metaphors and comparisons as analogies. They used analogous structures to share a relation, idea, pattern, attribute, function and the like. Analogies have played a prominent role in scientific explanation, insight, and discovery. Kepler, an astronomer, drew an analogy between planetary motion and clockwork. Bohr made an analogy between the atom and solar system.

A wider notion of analogy was used by contemporary cognitive scientists, who brought out the Structure Mapping Theory (Gentner, Holyoak & Kokinov, 2001), which is similar to the mapping between the source and target used by the conceptual metaphor theorists. According to this view, analogy depends on the alignment of the elements to show the relation between the source and the target. It is not surprising that authors and teachers routinely use analogies when explaining science concepts to students (Harrison & Treagust, 1993, 1994; Thiele & Treagust, 1994; Treagust, Duit, Joslin, & Lindauer, 1992). Thiele and Treagust (1994) investigated the extent of analogies used in chemistry textbooks and found that a total of 93 analogies were identified from the ten selected textbooks. Among them, 47% of the identified analogies had a pictorial representation of the analog. Analogies are believed to help student-learning by providing visualization of abstract concepts, by helping compare similarities of the students' real world with the new concepts, and by increasing students' motivation (Duit, 1991a).

Analogies are more motivating when students feel their ideas and views have been incorporated into analogy construction (Harrison & Coll, 2008). Analogies, while helping to simplify a concept, help students to acquire the skills needed to examine a concept from a number of different perspectives, sort out pertinent information, appraise the significance and construct knowledge, rather than just passively associating a key concept with a definition. This approach may help students to perceive with deeper understanding and learn the concept holistically, resulting in long-term retention due to their active participation. As they solve and create analogies, students actively process information, make important connections, use information and skills to identify relationships, construct relationships and generate new knowledge, and improve understanding and long-term memory (Libonate, Brunner, Burde, Williams & Libonate, 2004). An analogy could be a diagram, real life example, cartoon, allegory, parable, pair of words which have similar relationships, metaphor, game, paper craft, mime, an animation clip or anything else that is created by an imaginative teacher to enable a student to participate actively in order to grasp the concept.

2.5.1 Teaching With-Analogies (TWA) Model

A task analysis is a technique that identifies the basic processes that underlie expert performance of a task (Goetz, Alexander, & Ash, 1992). The Teaching-with-Analogies Model (Glynn, Duit, & Thiele, 1995) was initially based on the task analysis of certain prescribed science textbooks and examined the analogies of exemplary teachers and textbook authors. TWA model provides certain guidelines for using analogies. Glynn (1991) acknowledges that teachers and authors often use analogies, without being aware that they are presenting an analogy. The teachers, while responding to student questions or explaining an incomprehensible complex concept, seek help from a familiar situation and introduce or compare the concept using expressions such as 'similar to' and others. In the TWA model, the goal is to transfer ideas from a familiar concept (analog) to an unfamiliar one (target). If the analog and target share some similar features, an analogy can be drawn between them. The process of comparing the features is called mapping. The teachers are cautioned that they need to ensure that the teachers' and authors' analogies do not add to already existing alternative conceptions. The TWA model proposes six operations that the teacher carries out when drawing an analogy. They are: introducing the concept, reviewing the analog, identifying the corresponding features of the concept and analog, mapping the similarities, indicating where the analogy breaks down and drawing conclusions about the target concept. It has been understood that children perceive an analogy as an initial model of the target concept and they draw on their existing knowledge to grasp the significance. When the students learn more about the target concept, it is anticipated that they will 'outgrow' the analogy and adopt more sophisticated mental models of the concept. The need to establish students' familiarity with the analog is crucial to proceed further on to the next stage. Moreover, there is a chance of missing out one of the six operations while presenting the analogy, which might adversely affect the outcome.

2.5.2 Bridging Analogies Approach

Brown and Clement (1989) developed an approach to find a continuous passage toward the science view from the facets of students' conceptions that are mainly in accordance with the existing science view. Analogy is a comparison between two things. The key idea in this approach is to facilitate this passage by a series of 'stepping stones' that are designed as bridging analogies. It is vital that the students understand how the analog and the target differ in their attributes to avoid alternative conceptions. The Akron Global Polymer Academy (2001) recommends the use of multiple analogies, based on their research findings, 'Sometimes multiple analogies must be used to teach the same concept. Use of multiple analogies in a bridging sequence has been successful in helping students make sense of initially counter-intuitive ideas' (AGPA, 2001). In this case, it is not just bridging a single analog and a target, but bridging a number of analogs with the same target to accomplish thorough learning with minimum alternative conceptions. Multiple analogies allow the full gamut of student experiences to be utilized (Harrison & Coll, 2008).

2.5.3 The FAR Guide

The FAR Guide is a systematic format for presenting analogies (Venville, 2008). The inadequacies in TWA approach led to the development of the FAR Guide, which consisted of reduced number of operations, but with emphasis on pre-lesson focus and post-lesson reflection, under the guidance of Treagust, Harrison and Venville (1998). There are three stages specified in this approach viz. Focus, Action and Reflection, which gives the acronym, FAR. In addition, a teaching guide for this approach was also prepared by the authors, which contained sample analogies for the teachers to model. The purpose of the FAR Guide is to help teachers maximise the benefits and minimise the constraints of analogies when they arise in classroom discourse or in textbooks (Treagust, Harrison and Venville, 1998).

The presentation of analogies proceeds in three stages:

Stage 1. Focus: The teacher chooses an appropriate analogy, preferably from the students' world, which corresponds to the scientific concept and plans how to present the analogy effectively, knowing the difficulties associated with teaching and learning of the particular concept. It is essential that the teacher knows the preconception of the students on the chosen analogy and concept. This could be done by giving the students a short test or asking informal, open ended and closed questions. This gives the cue as to whether the teacher should go on with the planned analogy. This also prepares the teacher to present the analogy, focusing on the needs and deficiencies of the students.

Stage 2. Action: This step is a planned activity of mapping to bring out the shared and unshared attributes of the analog and target with the class. During analog-target mapping, the students put up the structural and functional differences between the analog and target, followed by discussion and a guided comparison by the teacher to eliminate alternative conceptions. The teacher clearly draws parallels between the students' thinking and the actual concept so that alternative conceptions can be minimised. The discussion continues till the students become familiar with the features of the analog, identify the shared attributes and know where the analogy breaks down. At this stage, the teacher has the choice of involving the students to generate their own analogies for the same target and share with the rest in the class. This kind of repetitive reinforcement has the potential to bring about deep understanding of the concept and long term retention.

Stage 3. Reflection: This is the third step stipulated in the FAR Guide by Treagust, Harrison & Venville (1998), which describes the procedure as: 'Following the presentation of the analogy, teachers reflect on the clarity and usefulness of, and conclusions drawn from, the analog and consider ways in which the analog, the mappings, or the analogy's position in the lesson may be improved'. The teacher looks at all the aspects of presentation for improvement and in particular, checks for student understanding. This could be in the form of an open questionnaire, where a student has the option of being anonymous and has more freedom to express to give honest opinions, either on the use the analogy or behavioural aspects of learning or a set of closed questions. Open discussions and interviews are likely to help to find out whether the students were benefited by the presentation. All these actvities and self reflection, will guide a teacher to know whether the topic has to be reviewed or is already imprinted for long term memory.

Teaching with analogies has to be a brain compatible learning based on the research findings by Kirchhof and Buckner (2006, p. 268), who reported:

> Specifically, our analyses identified four distinct strategies that were variably adopted by participants during intentional encoding. Two strategies—verbal elaboration and visual inspection—showed evidence of separate contributions to memory performance and were associated with brain activity in distinct prefrontal and extrastriate regions during intentional encoding. Activity in regions associated with use of these effective encoding strategies was also correlated with individuals' memory performance. …results suggest that use of multiple encoding strategies can augment memory performance, and that different encoding strategies can make independent, additive contributions to memory performance.

All the four main strategies identified by Kirchhoff and Buckner such as visual inspection, verbal elaboration or word-based, mental strategy, and memory retrieval strategies are all included in this single strategy of teaching with analogies. A visual analogy presented to students leads to visual inspection by the students, where as the analog-target mapping process by the students, facilitated by the teacher, ensures word-based elaboration and mental strategies, and finally, during 'Reflection' and after the presentation, memory retrieval plays a significant part in learning using analogies. We can presume that the FAR Guide allows sufficient time for the brain to integrate the information given to students and promote long term retention, because all the specified steps for an analogy take at least two or three teaching sessions to complete. Moreover, it is not too ambitious to presume that sleep dependent learning also can occur, since science classes are held on different days of the week with sufficient time for the brain to 'sleep on' and integrate the gathered information. Caine's 12 Brain/Mind principles underpin the tactics adopted in teaching and learning with analogies approach.

2.6 Summary of the Chapter

The research informed me that:

Most of the learning theories support the principles involved in teaching with analogies.

Incorporating analogies to teach and learn scientific concept is an effective teaching strategy, where learning is dynamic and interactive under the facilitation of a constructivist teacher.

The FAR Guide, 'a systematic format for presenting analogies' helps teachers to 'maximise the benefits and minimise the constraints of analogies when they arise in classroom discourse or in textbooks'.

The goal in incorporating an analogy to teach is to simplify a complex scientific concept by offering a familiar ground for the learner to understand an unfamiliar situation, thus effecting conceptual change.

Listing likes and dislikes between an analogy and a target in analog target mapping helps students to establish connections between what students already know and what they would be learning. This reduces alternative conceptions.

The students exercise critical judgement and creative thinking to gather, evaluate, and use information for effective problem solving and decision-making through analogies. Meaningful learning occurs through rethinking old ideas and coming to new conclusions about new ideas which conflict with old ideas, thus reducing alternative conceptions.

The students create their own knowledge, both real and imaginary and they work to identify and develop their own theories. When expected events occur, students assimilate them into their pre-existing knowledge networks, but when unexpected events occur, students accommodate the discrepancy by restructuring their knowledge network.

Conceptual change occurs at concurrent stages, when the student identifies the view presented by the teacher intelligible, meaningful, plausible and harmonious with his or her conceptions for easy reconciliation. This enabled higher metacognitive processing and evolved new ideas to engage in metaconceptual activities.

An appropriate analogy acts as an effective temporary substitute to remove alternative conceptions till the learner develops the correct perception of the target, resulting in proper understanding and long-term retention.

Bridging a number of analogs with the same target through student generated analogies seems to accomplish thorough learning with minimum alternative conceptions.

When students are encouraged to create their own analogies for the same scientific concept and share with the others in class, an opportunity is given to develop more sophisticated mental models of the concept and attain metacognitive awareness.

Students, who are exposed to and who become skilled in generating their own analogies and in the use of multiple analogies, find it easy to develop a more scientific understanding of science concepts, perhaps due to the neuroplasticity of the brain.

The learners get motivated and readily participate with sustained interest when the analogies offer visual, auditory, tactile and kinaesthetic stimuli and multiple learning experiences.

Learning science using analogies could be considered as brain compatible since the students construct new information based on familiar experiences. Repeated analog-target mapping is likely to establish patterning in the brain, which might lead to seeking similar situations such as an analogy to understand a complex phenomenon. Sometimes in this attempt students may generate their own analogies for better understanding and retention.

Chapter 3

Analogy 1 – 'Fill Up the Orbit'

3.0 Introduction

This chapter begins with a brief description of the significance of offering visual stimuli to students for better perception and understanding; visual analogies were used to represent the chosen scientific concepts in this investigation (Section 3.1). The basic structure of atoms and molecules was taught to the students of Year 8 by incorporating an analogy game, 'Fill up the Orbit'. The methodology describes how the FAR Guide was adapted to suit the presentation without deviating from the requirements specified in the Guide. The procedures during the Focus, Action and Reflection stages and the associated student materials handed out to the students follow (Section 3.2). The details of the two-tier diagnostic test results, which contributed to the quantitative data, analysis of these results and their statistical significance are shown for the whole group and based on their gender (Section 3.3). Further, the qualitative data collected from the questionnaire, opinionnaire, observations, interviews and students' reflective comments have been added and their significance has been interpreted in relation to the effectiveness of the presentation of the analogy. The peer review consists of comments from two supervised pre-service teachers during this period (Section 3.4).

Related to this chapter is Appendix A which consists of the details of the intervention showing how the analogy game was adapted to the FAR Guide requirements, flash cards used in the game, analog -target mapping sheet, (A.1. a, b, c) and the FAR Guide (A.2). Section A.3 shows the rules of the game and how the game was played. A.4 shows a few pictures taken during the game. Section A.5 contains the two-tier diagnostic test questions on the atom and Section A.6 shows the analysis of the individual answers. A table is included to show the increase/decrease percent of the correct answers, and alternate conceptions. A.7 consists of graphs, which display the results of the pretest and posttest of the whole group and based on gender. Section A. 8 shows the opinionnaire, which elicited the students' reflective comments and Section A.9, contains the questionnaire used to probe the students' thought process on atoms and molecules. Finally, the frequency tables used in the statistical analysis of the results are added.

3.1. Visual Analogies

Smith (1994, p. 85) quoted Aristotle, the great Greek philosopher, on the subject of 'Soul' that the soul never thinks without an image. A study conducted by the Institute for the Advancement of Research in Education in the United States (2003), identified and evaluated 29 scientifically based research (SBR) studies and concluded that visual learning improves student performance in critical thinking, organisation, comprehension and retention. The researchers also noted that students explore information in a dynamic inquiry process and discover meaning from the visual information. The above observations offered the incentive to create and design all the analogies as visual and pictorial, incorporating most of the student-preferred characteristics. It was hoped that such an analogy might stimulate the higher order thinking faculties of the brain. Since technology takes advantage of the visual elements and enables mental links to apply graphical and three-dimensional models to understand new materials, computer technology was used to generate colourful pictures to depict the analogies. It was well received and with sustained interest when projected on the screen. The following incidents indicate that the students enjoyed the visual analogies presented to them. Conor, from Year 8, requested a copy of the analogy for the cell (a soft drink factory), for which, he said, he would pay the quoted price. Another student in Year 11, Azhee, expressed his wish to own a copy of the animated analogy for the Quantum Mechanical Model. These requests show that the used visual analogies were appealing to these students.

The decision to add an analogy game in the research was to make the best use of students' interest in playing games. The details of the atom were given as rules of the game, 'Fill up the Orbit' game, which initiated student participation straightaway. Designing it as an outdoor game made it even more attractive to students. At the end of the term, the students requested that we played the game once again inside the classroom during the revision for the unit test. The students moved the chairs and desks to make place for the game voluntarily, without a protest, which was otherwise considered cumbersome. Though it was indoors, the students still enjoyed the game and reinforced their knowledge before their unit test.

3.2 Methodology: Atoms and Molecules – A game to play

3.2.1 Rationale

The purpose of the research was to evaluate the effectiveness of using the FAR Guide to teach science with analogies and to find out whether this approach has the potential to enhance student understanding of complex scientific concepts. Consequently, it was imperative that appropriate analogies were chosen or designed for maximum perception by the students and easy correlation with the target. While the speculation is that students are likely to gain deep understanding of the concept and hold minimum or no alternative conceptions if they are presented with an appropriate analogy having maximum shared and minimum unshared attributes with the target, it is vital that appropriate analogies are chosen or designed to achieve the desired outcomes. Moreover, the chosen concept has to be one of the topics included in the school's work program. Further, these concepts would have to be comprehended with deep understanding and should lay a strong foundation for easy construction at higher levels; also help students to obtain good grades in their current tests and examinations. Consequently a well-structured approach has to be adopted to present the analogy; one, which would achieve easy assimilation of the target and bring about deep understanding of complex concepts and as stated earlier, the FAR Guide was chosen.

3.2.2 The Intervention Using the FAR Guide

Analogies are a quick and interesting way to explain non-observable science objects such as atoms and abstract processes such as gene action. However in their research Venville and Treagust (2002) found that some popular analogies used by science teachers were ineffective. This was the impetus for the development of a model that can be used for improving teaching with analogies (Venville, 2008, p. 23). Although Treagust (1989) expressed the opinion that there was not enough empirical data on the systematic presentation of the FAR Guide as, "it is not certain for whom and under what conditions analogies are beneficial for learning and understanding", later findings of Treagust, Harrison and Venville (1998) showed that the 'Experience so far with the FAR Guide indicates that teachers and their students benefit from and enjoy analogies when teaching and learning science'. Considering the above views and to ensure that the presentation of the most appropriate analogies was systematic and definite, the specified steps given in the FAR Guide were strictly adhered to in the presentation of all the analogies. The procedures for using the FAR Guide are presented in Section 3.2.4. (Complete details of the 'Fill up the Orbit' analogy game using the FAR Guide are shown in Appendix A1-A3). All the analogies, including the analogy for the atom, were deliberately made quite different from the regular verbal comparison. This procedure helped to capture maximum attention of the students, though it was realized during and after the presentation that a few students had difficulty relating the analogy to the concept.

3.2.3 Sample

The sample consisted of two successive batches of Year 8 students (2006 & 2007). A total of 46 students, consisting of 22 girls and 24 boys, aged between 13 and 14 participated in this study. Since the students were at the introductory level, they were given only the essential fundamental details of atoms. It was ensured that the provided detail had the potential to provide an effective base for further studies in chemistry and related sciences.

3.2.4 The FAR Guide to teach Atoms and Molecules

Focus		
Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Atoms and Molecules' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with similar games like the chosen analog, 'Fill up the orbit'
Action		
Likes	Discuss the features of analog and the scientific concept. Draw similarities between them.	An atom could be compared to the chosen game, in which the central circle represents the nucleus of the atom and it contains the card showing the number of protons and neutrons. The students standing around in concentric circles represent the electrons. (The detail mapping is given below)
Unlikes	Discuss where the analog is unlike the scientific concept	The analogy game was designed to resemble the actual structure of the atom largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.
Analog - Target Mapping		
ANALOG	ANALOG – FEATURES	TARGET- FEATURES
The central circle	The card with the name, number of protons, and neutrons.	The nucleus containing protons, and neutrons of the atom.
The 1st outer concentric circle	A maximum of 2 students standing on the first circle.	Duplet rule – The first orbit can accommodate a maximum of 2 electrons.
The 2nd outer concentric circle	A maximum of 8 students standing on the second circle.	Octet rule - The second orbit can accommodate a maximum of 8 electrons.
The 3rd outer concentric circle	The remaining students were moved to the third outer circle. (only the atoms with electrons occupying the first 3 orbits).	Once the 1st and 2nd orbits have reached the maximum electronic configuration, the remaining electrons would fill in the 3rd orbit.
Completed 1st circle	Only 2 students are permitted to stay within the 1st circle.	The atom has attained complete and stable electronic configuration.
Completed 2nd circle	Only 8 students are permitted to stay within the 2nd circle.	The atom has attained complete and stable electronic configuration.
Incomplete 1st/2nd/3rd circles	Less than the maximum number that could be accommodated.	Incomplete/unstable electronic configuration.
Complete outermost circle	Maximum number of students filling up the circle.	Full valence shell/orbit. Stable electronic configuration.
If 1st/2nd/3rd circles are incomplete	If less number of students than the maximum that could be accommodated, students will move out or come in to complete the circle.	Can receive or give away electrons to attain a stable electronic configuration and get charged to form an ion or in some cases, the atoms share the electrons in the outer orbit.
Complete outer circle	Two students filling up the 1st orbit, 8 students, if it is the second or third orbit.	There are elements, which have complete outer orbits, such as the inert gases, will neither give away nor receive electrons from any other atom.
Reflection		
Conclusions	Was the analog clear and useful or confusing?	The students enjoyed the game. During analog-target mapping, the students brought up many likes and dislikes which listed on the board. They copied these points down (a copy has been attached on the following page. Later they were asked to answer a few questions and this tested their understanding thinking process. Many expressed that the game clarified a few of their uncertainties of the concept.
Improvement	Refocus as above in light of outcomes.	The analog will be refocused in the light of the above outcomes.

3.2.5 Preparation for the Pretest

The lesson on atoms and molecules was taught in class before the analogy was introduced. The lesson began with a brief introduction followed by a few questions to find out the students' preconceptions on atoms and molecules. It was found that the students were not exposed to the concept prior to this lesson.

To make it more tangible, a named element, Sodium, was chosen to show the structure of the atom. The students were introduced to all the essential, basic details associated with atoms and molecules. A diagram was drawn on the board and the structure of the atom was described. The students learnt about the atomic mass and number, symbol, nucleus, subatomic particles and their charges, orbits, stable electronic configuration and bonding, which results in the formation of molecules and compounds. The students were taught how to calculate the number of subatomic particles using the given atomic mass and number. They were also asked to calculate the same for a few examples. The concept of bonding was introduced with an example. Sodium and Chlorine atoms were drawn on the board and the transfer of electrons was explained. The students were also shown how an oxygen molecule is formed as a result of sharing electrons. The students were then asked to peruse a table of elements, which showed 25 elements, their symbols, atomic mass and number. They recognized that atoms in the table differed in their structure.

At this stage, the students were cautioned that they would learn about the sublevels of each orbit later, and the reason for the electrons occupying at different levels within an orbit. The Quantum Mechanical model was mentioned but not elaborated. The students were told that the orbits are imaginary and could be considered as something similar to the way the planets move around the sun. The electrons may not strictly move on the same line or path, but they are likely to be found within the space assigned to each orbit. The students were given the formula, $2n^2$, to calculate the maximum number of electrons that could occupy an orbit, where 'n' is the position number of the orbit such as 1, 2 or 3. They were also warned that there are exceptions to these rules. After the completion of these concepts, the students were given the two-tier diagnostic pretest and the answers were collected for analysis.

3.3 Quantitative Analysis of Results

3.3.1 Two-Tier Diagnostic Test

An adapted version of the Two-Tier Diagnostic Instrument designed by Treagust (1985) to fit the study of atoms and molecules (given in Appendix A 5) was administered to the students before and after the presentation of the analogy. This helped to identify student-understanding and alternative conceptions. The questions were framed carefully to test the students' understanding of atoms without omitting any of the basic details. For example, the following answers and reasons were given as choices for the first question:

How would you describe an atom?

Answer:

1) An atom is the smallest particle of a substance that cannot be broken down further.
2) An atom is the smallest particle of a substance that can be broken down further.
3) All elements are composed of tiny indivisible particles called atoms.

Reason for your answer:

a) I cannot see atoms; therefore it must be very small and cannot be divided further.
b) Many particles join together to make elements and these particles can't be divided.
c) I cannot see atoms; therefore it must be very small, but it can be divided further.

These choices reinforced the concept that all substances are made of atoms and at the same time, helped to find out the misconception that atoms cannot be divided further due to its small size.

Similarly, the following answers and reasons were given for the second question:

When is an atom neutral?

Answer:

1) When the atom has only neutrons.
2) When the electron number is equal to the neutron number.
3) When the electron number is equal to the proton number.

Reason for your answer:

a) If the positive and negative charges of an atom are equal, an atom will be neutral.
b) If an atom has to be neutral, it should have only neutrons.
c) If the neutron number is equal to the electron number, the atom will be neutral.

These questions aimed at bringing out the understanding of the structure of atoms in students such as the knowledge of the subatomic particles and the relative charges and what makes an atom neutral.

The choices also brought out the alternate conception that 'If the neutron number is equal to the electron number, the atom will be neutral'. The framing of the questions, which took a lot of time and effort, were aimed at eliciting maximum information on the students' understanding and alternate conceptions. Consequently, from the results and reflective comments evaluating the effectiveness of using the FAR Guide to present a concept incorporating an analogy and the use of two-tier diagnostic instrument were substantiated.

The same two-tier diagnostic test was administered during the following science period, which was a day later. The answer papers were collected and analysed. To make the test results valid and reliable, the correct answers were not given to the students and the students took the posttest without the prior knowledge of the correct answers. Cronbach alpha reliability measures for the pretest and posttest were 0.47 and 0.56, respectively.

3.3.2 Statistical Analysis of the Diagnostic Test Results (Appendix A10)

Table 3.1: A comparison of students' pretest and posttest total scores on the teacher-constructed 'Atoms' two-tier test using paired sample t-test statistic (N[46])

		Mean	Std. Deviation	Std. Error Mean	t value
Pair 1	TOTAL-pretest	4.52	1.92	0.28	3.25
	TOTAL-posttest	5.43	2.0	0.3	

A paired-samples t-test was conducted to evaluate the effect of the instruction on students' scores on the 'Atoms and Molecules'. The test showed an increase from the pretest (M=4.52, SD=1.92) to the posttest (M=5.43, SD2.0) t(45)=3.25, p<0.01). The Cohen's d statistic of 0.51 indicated a medium effect size. As indicated in Table 3.2, the students tended to improve their scores from pretest to posttest. Posttest results showed a statistically significant improvement as indicated by the scores. An average of 45.3% scored in the pretest was enhanced by 9.2% after the intervention (54.5). This seems to indicate that some of the students benefited from the presentation of the concept after the incorporation of the analogy. Incorrect answers less than and above 10% were classified as alternate conceptions. All the responses and which showed an exceptional increase or decrease were analysed (Appendix A6). The percentage of students who correctly answered the first tier and both tiers are shown in Table 3.2. The percentage of students' responses on most items is less when the two tiers are combined compared to the first tier only. The percentage on both tiers improved in the posttest.

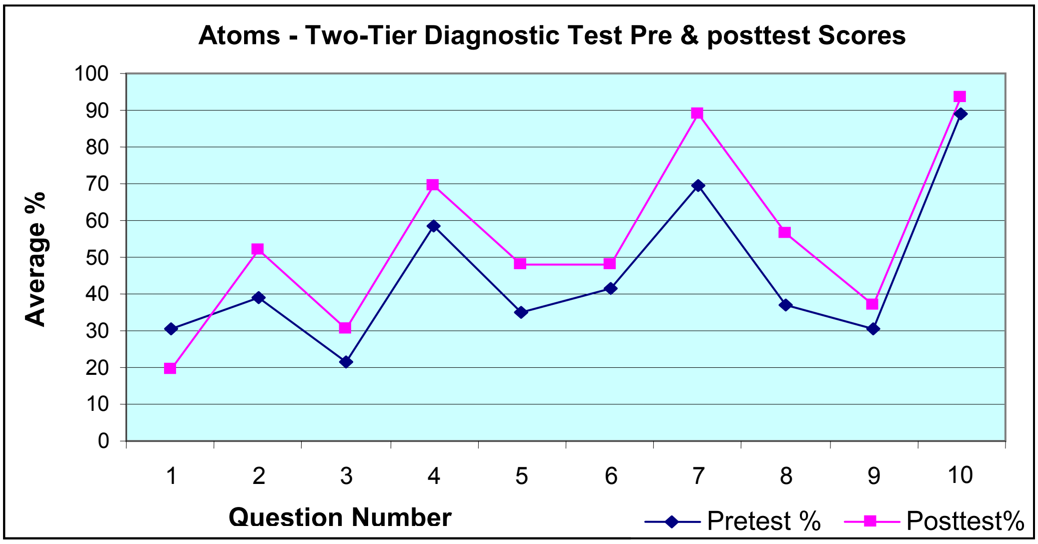


Figure 3.1: Average percentage correct scores on the two-tier diagnostic pretest and post test on the teacher-constructed 'Atoms and Molecules' diagnostic test (N =[46])

Table 3.2: The percentage of students who correctly answered the first tier and both tiers of the items in the teacher-constructed 'Atoms and Molecules' two-tier diagnostic test (N [46])

Question number	**'Atoms and Molecules'** Pretest — Percentage of students who correctly answered: first tier	both tiers	Question number	**'Atoms and Molecules'** Posttest — Percentage of students who correctly answered: first tier	both tiers
1	35	30	1	22	20
2	44	39	2	54	52
3	26	22	3	39	30
4	83	59	4	78	70
5	35	35	5	48	48
6	48	41	6	50	48
7	76	70	7	91	89
8	59	37	8	61	57
9	61	31	9	74	37
10	39	89	10	94	94
Mean	50.6	45.3	Mean	61.1	54.5

3.3.3 Analysis of Gender Differences Based on the Test Results

Overall, the test results presented in Figure 3.2 and table 3.3 shows that the girls obtained a higher average (48.2%) compared to the boys (42.5%) in the pretest; the difference between the boys and the girls being 5.7%. The posttest data average (in Figure 3.3) shows that the boys' score improved by 10% and girls' score by 8.2%. The decrease of 3.4% in the difference between the boys' and girls' scores indicates that the analogy helped in understanding the concept. The boys benefited slightly more after playing the analogy game than did the girls. The game seems to have benefited the students by presenting the essential details needed to understand the structure and behaviour of atoms directly or indirectly. This in turn might have helped the students to answer more number of questions correctly. The boys showing an improvement of 10% in their average as against the girls, who had an increase of 8.2% in the posttest, came as a surprise, since the girls generally performed better in class tests. The annual class average showed that the girls' average in science exceeded the boys' average by 4%.

Table 3.3: Statistical analysis of gender differences in their performance (n 46)

Concept	Pretest Means		Pretest SD		Posttest Means		Posttest SD	
	Male	Female	Male	Female	Male	Female	Male	Female
Atoms	4.04	4.55	1.66	1.44	4.87	5.36	1.78	1.62

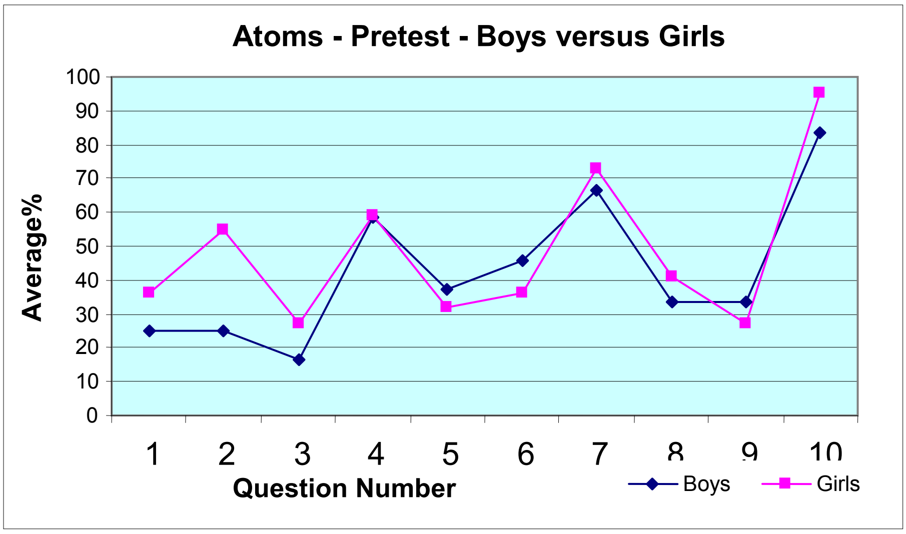


Figure 3.2: Average percentage correct scores on the two-tier diagnostic pretest on the teacher-constructed 'Atoms and Molecules' diagnostic test for boys and girls (N [46])

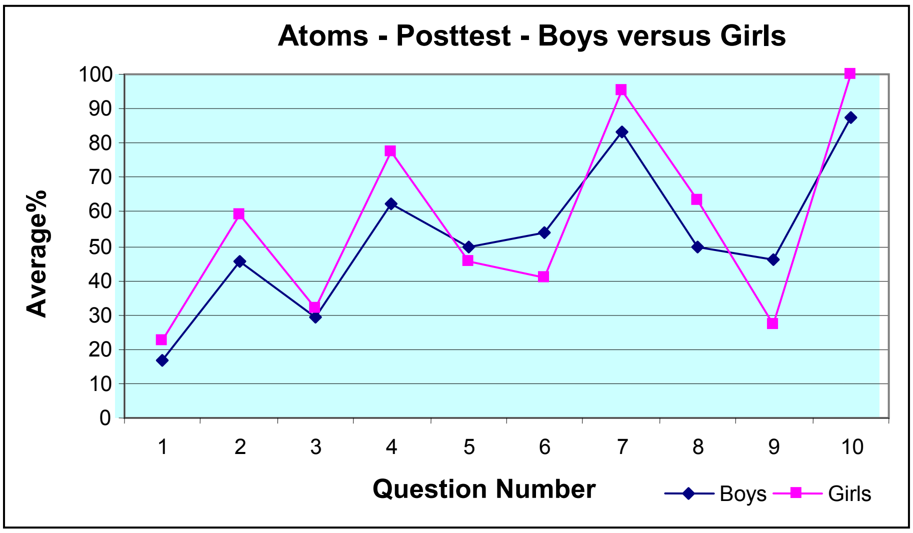


Figure 3.3: Average percentage correct scores on the two-tier diagnostic post test on the teacher-constructed 'Atoms and Molecules' diagnostic test for boys and girls (N [46])

3.4 Qualitative Analysis

Neill (2006, p.1) quotes Strauss and Corbin (1990) in his 'Analysis of Professional Literature' and defines qualitative research as, 'any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification'. Written description by the participants, observations and interactive interviewing were the three methods adopted to collect data for qualitative analysis. Analysis of the qualitative data obtained in this study, after the incorporation of the analogy to teach the details of atoms and molecules, indicates that both the quantitative and qualitative data complement each other and give a comprehensive understanding of the results obtained. Since there was time to spare after completing the school's work program, it was decided to explore further on the effectiveness of this particular analogy. The students were asked to write the description of their thinking processes on the understanding of atoms and molecules by responding to certain guiding questions. This was done exactly one month after playing the analogy game. These questions are given as Appendices C and D under the 'Review of the analogy game' and 'Questions to probe the Thinking Process' respectively. The answers were compiled and analysed for their significance in relation to the effectiveness of the analogy. The students were closely monitored and studied during the analog-target mapping and when they played the analogy-game to understand their responses and behaviour. Video-recording and photographs helped to enhance the contextual validity of the data. A few students were chosen at random and interviewed to get a verbal description of their experience.

3.4.1 Opinionnaire

'The opinionnaire or attitude scale, is an information form that attempts to measure the attitude or belief of an individual. How one feels or what he believes is his attitude, which can't be measured or described. The researcher, therefore, must depend upon what the individual says are his beliefs and feelings. From the statement of his opinion his attitude is inferred' (Key, 1997). An opinionnaire was prepared to know more about the understanding of atoms and molecules and the students' attitude towards learning a scientific concept using analogy as a tool. Due to time constraints, only 23 students, i.e. 50% of the chosen cohort (11 boys and 12 girls), took part in writing the details of their thought process. This offered valuable data and the analysis of which has been presented on the following page. Of the 23 participants, 21 students were able to pick the right combination of atoms, which were likely to form a compound and they were able to explain the octet rule. These students discarded the other two choices because they discerned that bonding will not result in attaining a stable electronic configuration and hence, those discarded atoms will not combine with the given atom. This revelation is significant because unless the students had understood and remembered the concept, they would not have answered the question correctly. Presuming that a mental process occurred associating the question and their thinking, they were asked to identify the mental stimulus, or 'what came to their mind', which prompted them to give the particular answer. Twenty two students revealed what came to their mind and their answers were collated and analysed. The following table gives the interesting details presented by the students:

Table 3.4: Identified Mental Stimuli

Mental stimulus	No. of students
Picture of the atom alone	3
Words associated with atoms alone	5
Analogy game alone	3
Picture & words	1
Picture & game	3
Words & game	3
Pictures, words & game	4
No response	1
Total	23

The analysis was done not by looking at the individual answers alone, but considering all of the student's responses by carefully scrutinizing the entire script as a whole, to get a better perception of the student's understanding and views. Of the 23 students, 17 students remembered the analogy game while answering the questions. The game was mostly remembered in association with either the related terms or diagrams. Those who remembered the game, mentioned the salient features of the game such as the rules, how they played the game in detail, how the students moved to complete an orbit and to attain a stable electronic configuration. A few significant incidents during the game were also described in the answer sheet. For example, 'I remembered and I visualised every one in my class, the class was split into two groups, boys and girls, … two girls in the inner circle and six girls in the next', 'I remember, if the boys only had 7 electrons on their outer orbit Fairuz had to be shared (means moved to the boys' group) to make (it) stable because we only had one in the outer orbit which we didn't need', 'orbits drawn with chalk on the floor', 'people standing in circles, electrons', 'we gave one to the boys team', are a few examples to show that this analogy was effective in teaching the concept. It was significant to note that 18 out of 23 students drew a correct generic diagram of a noble gas, using their own imagination. They were given neither the atomic mass nor the number. This indicates that the analogy game did benefit the students in understanding the concept. 13 students wrote that the game would help to retain the details of the atom in their long term memory, where as three felt that the explanation given in the class would help in long time retention. The others were neutral to the issue. 15 students said that they preferred the teacher teaching them with analogies, seven preferred without the analogy and one student failed to write an answer.

3.4.2 Observations

Key (1997) explains observation as one of the data tools in research thus: 'systematic direct observation of behaviour is the most desirable measurement method. An investigator identified the behaviour of interest and devises a systematic procedure for identifying, categorizing, and recording the behaviour in either a natural or "staged" situation (p. 2)'. The students under study were observed carefully in class and at the venue, where they played the game. The students displayed keen interest to know, understand and win the game. It seemed that the boys were more enthusiastic than the girls and the quantitative data collected showed that the boys enhanced their average scores more than the girls after the game.

The following comments affirm that the game was motivating and inspiring and helped the students to remember the concept:

- because we were like in an atom. We played a game and got involved so I remembered it better – Jayden
- I can actually remember doing it, discussing it and explaining why. The analogy is easy to remember and less likely people will get bored and not listen- Frances
- It is easier to remember if it was fun. – Sal

3.4.3 Interviews

Due to time constraints, lack of privacy when the students were available and the need to complete the work program before the commencement of the examination, the interviews had to be rushed and completed. Five students were picked at random and interviewed. Unfortunately, only two were forthcoming with their opinions. When analysed, it was revealed that the responses were essentially the repetition of what had been expressed in the opinionnaire and review of the analogy sheet. The responses given during the interview complemented the above two data tools and brought out a large quantity of the needed information to know the students' stance.

3.4.4 Higher Order Thinking

Higher order thinking was evidenced in the students' responses for the 'thought probing questions'. 91% of the students had acquired the understanding to choose the right kind of atoms which would bond readily by discarding the incompatible ones and 78% drew a generic diagram of a noble gas without any assistance such as the atomic mass or number. The ability to transfer what was learnt as a game to answering the questions in class and tests by the majority of students indicates a favourable conceptual change and higher order thinking brought about by the analogy.

3.4.5 Students' Reflective Comments on the Effectiveness of the Analogy

The following pages contain are a few quotations, which show how the analogy game helped the students' in understanding and remembering the concept and at the same time making science learning enjoyable:

Understanding

- 'I prefer teacher using analogies to simplify structure and functions of objects, as it is a great way to learn as it puts the subject to things I know'. (Tayla)
- '. . . it gets very interesting to be able to experience the feeling, to be able to teach yourself'. (Jayden)

- '. . . we had a chance to be inside or feels what it is like to be inside an atom'. (Alex)
- 'I figured out (the answer) because actually doing it'. (Monica)
- 'The game allowed me to see the functions of an atom in an easier way'. (Cara)
- 'The game - when sharing electrons or just creating the orbits allowed a much more clearer way of seeing and knowing the behaviour of an atom' (Eryn)
- 'The game 'cause it gave me a better understanding of an electron by being one'. (Koshin)
- 'The game was fun, yet educational at the same time, it was an awesome game!!!' (Lochlan)
- 'It was a game which taught us a lot by our friends, helping us learn' (Tessa)
- '…it was easier for me to understand (atomic structure) when we did it physically' (Max - hearing impaired)
- '(I prefer) The analogy game, because it is hands on. The interactive lesson sticks more in my mind because I actually had to think about what I was doing as opposed to sitting in class and just listening. (sometimes going in one ear and out the other. You had to think to get it right and it was hands on. I learnt about the atom from the combination of the lecture and the game. I needed both because after the lecture I wasn't completely sure of the information so the game helped me. I visualised the diagram on the board and the game played'. (Tayla)
- 'I learnt about atoms when we played the game and only started understanding it then. Definitely (I prefer), the atom analogy game we played because we played many sets of it and it carved into you. It also was funner and I understand it better and it was more interesting because we had discussion'. (Elif)

Memory and Retention

- 'When I do something, I remember it'. (Ha)
- 'As it is a different way of learning and so it will remain in my tiny head'. (Philip)

- 'The game was fun, which will help us remember it longer, where as a lesson, where a teacher just names and tells us about the functions of an object is boring and will be easily forgotten'. (Tayla)
- 'It was a group thing and I always remember everything we did, if it was interesting (which it was). (Kozhin)
- 'Game because we were like in an atom. We played a game and got involved so I remembered it better'. (Jayden)
- 'Real life analogies are easier to remember for me because it displays a real life situation. I found the class game more interesting because while having fun you can remember more because you are enjoying yourself'. (Eden)
- 'I can actually remember doing it, discussing it and explaining why. The analogy is easy to remember and less likely people will get bored and not listen'. (Frances)
- It is easier to remember when you are doing it with other people'. (James)
- '…for it is easier to remember stuff when you have fun'. (Finn)
- ' I visualised the atom like a solar system. Example: The sun in the centre of the solar system and all the planets orbiting around them' (James)

Learning Science is Fun

- ' . . . analogy game because it is interesting and fun, because it shows how deep you can discover the characteristics of an atom'. (Hamish)
- '. . . we had fun and learnt about atom, while we did it, And got to go outdoors for fresh air'. (Elif)
- 'Atom-analogy game (is more interesting) because everyone was having fun and we all got to work together and learn from each other'. (Sarah)
- '… the atom game because we had to put our knowledge to test so we could win'. (Billy)
- '…the analogy game, it was interesting and it was outdoors'. (Abby)

At the end of the year, one batch of the Year 8 students was given an opinion survey, to find out the students' views about incorporating an analogy in science. This included a few statements requiring a response (given in Table 3.5. on the following page). Of the 25 students 52% strongly preferred to learn using visual analogies, 56% using outdoor analogy games, 68% using hands on analogy activity and 48% preferred using analogies with any one or more of these features. 44% moderately preferred learning concepts using visual analogies, 36% as a game, 32% as hands on activity and 48% in any form. 4% of the students did not want to learn using analogies, neither as a visual nor as a hands on activity and 8% did not prefer a game analogy. 40% of the students strongly agreed that analogies made complex concepts simple and 48% moderately agreed on this and 12% did not believe that analogies simplified the concepts.

Table 3.5: Students' preference on using analogy in learning (n [25])

	Statement requiring a response	Very much	Moderate	Not at all
1	I prefer an analogy (a *comparison* in the real world) related to the topic explained to me with a picture to get me interested.	13	11	1
2	I prefer the analogy to be a game like the one we played for the atom to get me interested.	14	9	2
3	I prefer the analogy to be a hands on activity with materials to get me interested.	17	8	-
4	I prefer an analog presented with any one or more of the above features to get me interested.	12	12	1
5	Analogies make complex concepts simple and easy to understand.	10	12	3

3.4.6 Peer Review

Two pre-service teachers were involved in the study. One of them, Vidler, assisted in conducting the analogy game, took pictures and video-recorded student-behaviour during the game. Both the teachers were requested to review the strategy and give their comments. Their comments were mainly directed towards the two-tier diagnostic instrument on atoms and molecules. Vidler designed a few 'scientific process questions' and tested the students on atoms and molecules as a part of his teaching practice. The students scored an average of 65.6% in the test and the scores were used for reporting. Vidler considered questions 2 and 4 -10 as good questions. He wrote, 'Q.1 – 'wording of answers' make correct answer a little ambiguous. So for level of students may not get a good indication of thinking – i.e. may produce a lot of guesses'. Regarding Q.3, he felt that the second answer also should be considered correct. This cannot be because the question asks specifically for the nature of the atoms in one element and does not ask for a comparison. He felt that there was ambiguity at the beginning of the test, but the target level was good. He reckoned that the alternative conceptions were well covered in the latter part but questions 1 and 3 might not give an indication of understanding.

The second pre-service teacher, Ruth, gave the following account after reviewing the questionnaire on atoms and molecules.

> Nothing can be more abstract to students more than atoms and molecules, things at the molecular level that they cannot see with the naked eye.
> I found the questionnaire to be somewhat difficult. I think it would be hard for students to decide which answer is correct because they are very similar, hence, they may have problems cancelling questions out.
> The questions however, get easier as they progress.
> Again, I feel that it depends on, well, the students and at abstract thinking.
> Not very much content knowledge necessary but being able to visualize the atom is important.

The above two reviews indicate that the questionnaire was not deliberately made easy to help the students score higher averages. The students had to understand the questions clearly, sift out the essential details from the non-essential information and pick the correct answers and the corresponding reasons.

In conclusion, both the quantitative and qualitative data seem to indicate that the students did benefit from the presentation of the details of atoms and molecules when the analogy game was incorporated as per the specification given in the FAR Guide. The statistical analysis of results indicates that the students have shown a significant improvement after the presentation of the analogy. This shows that incorporation of analogies in science teaching using a structured, systematic approach such as the FAR Guide could be advantageous to students in learning complex scientific concepts.

3.5 Summary of Chapter

The research informed me that:

Technology based visual elements establish mental links readily and enable the students to apply graphical and three-dimensional models to understand new materials, which evoke sustained interest. The majority of the students seem to prefer learning with visual analogies.

Analogy presented as a competitive game, especially as boys versus girls, appeals to the students to bring out their enthusiasm and whole hearted participation. This makes them strive hard to absorb and retain what they have learnt and apply them in order to win the game.

Active participation in games enables students to retain the involved principles in memory for a long time. The students remember science concepts by mostly associating them with the mental pictures of the game, visuals and diagrams.

If and when the two-tier test questions are framed to bring out student understanding, the extent of retention, alternative conceptions and higher order thinking, it serves as a remarkable testing tool and guides a teacher for further action.

An analogy game has the potential to enhance the understanding of a science concept and reduce alternative conceptions. Analog-target mapping, application of the rules of the game and opportunity to generate their own analogies improve students' ability in cognitive processing and higher order thinking.

The students enjoyed learning through hands on activities and analogies than just listening to a teacher, who adopts the 'chalk and talk' strategy.

In this instance, the boys performed better in the posttest than the girls, indicating that boys benefit more from games to which learning principles are applied.

The analogy game enhances 'bonding' amongst the students since they work together as a team and this improves their personal and work-relationship, benefiting each other.

A few students 'loosen up' and interact better with each other and the teacher as a result of such informal outdoor activities in learning.

Higher order thinking was evidenced in the students' responses given for the 'thought probing questions'. The ability to transfer what was learnt as a game to answer the questions in class and tests by the majority of students indicates higher levels of thinking and the effectiveness of the analogy in bringing about a favourable conceptual change.

Chapter 4

Analogy 2 – Cell - A Soft Drink Factory

4.0 Introduction

This chapter begins with a brief description of the underlying rationale which gave the initiative to choose the basic structure of a cell as the next target to teach the students of Year 8 by incorporating a visual analogy of a soft drink factory (Section 4.1). The methodology describes how the FAR Guide was adapted and used to present the concept without deviating from the requirements specified in the Guide. The procedures during the Focus, Action and Reflection stages and the associated teaching materials handed out to the students are also in Section 4.1. Details of the two-tier diagnostic test results, which contributed to the quantitative data, analysis of the results and their statistical significance for the whole group and based on gender, qualitative data collected from the analog-target mapping sheet, class observation and discussions, and reflective comments and their significance are included in Sections 4.2 and 4.3. Unfortunately, the peer review from the pre-service teachers failed to provide any constructive comments or suggestions for this analogy and are not added. This chapter links with Appendix B consisting of the analogy diagram, two-tier diagnostic test questions, analog-target mapping worksheet, an opinionnaire to elicit students' reflective comments on the analogy on the effectiveness of the analogy, student generated analogies for the cell and organelles and finally, the frequency tables used in the statistical analysis of the results.

Related to this chapter is Appendix B which begins with the analogy diagram (B.1 a) which shows the cell as a soft drink factory, followed by the analog-target mapping sheet. B.2 shows the FAR Guide adapted to teach cell structure and function; this also shows the analog-target mapping in detail. B.3 contains the two-tier diagnostic test questions on cell and Section B.4 shows the analysis of the individual answers. A table is included to show the increase/decrease percent of the correct answers, alternate conceptions. B.5 consists of graphs, which display the results of the pretest and posttest of the whole group and based on the gender. Section B. 6 shows the opinionnaire which elicited the students' reflective comments and finally the frequency tables used in the statistical analysis of the results are added.

4.1 Methodology: Cell A as a Soft Drink Factory

4.1.1 Rationale

The structure and function of the cell and cell organelles are another mind-boggling concept for young students. Since it is not possible for the students to observe the minute details of the organelles and how they function, they are unable to comprehend how these could perform such complex functions to keep an organism living. Many a time, I have observed that many of the students swap the roles of organs and organelles, even at higher levels of study, giving the reason to choose cell as the next target. Many options were considered before choosing a soft drink factory as the analogy for a cell. The designing process began using the computer and a functioning soft drink factory was depicted in the diagram, making changes constantly and linking with cell and organelles via short notes until it was structured closer to a cell.

4.1.2 Sample

The sample chosen for this investigation to present the cell analogy consisted of 38 students, aged between 13 and 14. Since the students were at the introductory level, they were given only the essential, fundamental details of the concept, but this had the potential to provide a solid foundation for further studies in biology and biology-related fields.

4.1.3 The Intervention Using the FAR Guide

By the number of messages and articles posted on the Internet and researches undertaken on cell analogies, it is very clear that cell is one of the scientific concepts, which needs to be made simple for the understanding of students using a precise, structured approach. A single analog of a soft-drink factory was designed for this purpose. This analog contained all the components correlating to the cell organelles in a cell. Every step was carefully planned and adopted as per the instructions given in the FAR Guide (Treagust, Harrison & Venville, 1998). The analogy had all the desired characteristics, which were appealing to the students. (The analog diagram and details are given in Appendix B. 1, 2 & 3).

4.1.4. The FAR Guide for Teaching and Learning Cell Structure and Function

Focus		
Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Cell –Structure and Function' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a soft drinks manufacturing factory.
Action		
Likes	Discuss the features of analog and target. Draw similarities between them.	A cell could be compared to a soft drinks manufacturing factory, where each worker is responsible to carry out a particular function, exactly like the organelles of a cell (The details are given below).
Unlikes	Discuss where the analog is unlike the science concept.	The analog resembles the actual structure and function of cells largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.
Similarities mapped out in detail (Given to students as a hand out)		
ANALOG	**ANALOG -FEATURES**	**TARGET**
The building	A shed supported by beams, pipes, etc.	The cell supported by cytoskeleton.
Central computer	Contains all the information needed to regulate the activities in the factory; such as: recipe for the soft drink, names and quantity of the ingredients, details of processing, shipping and billing instructions, etc.	Nucleus contains the DNA, which has the codes for all the proteins to regulate the activities of the cell.
Computer print out	Contains instructions to collect and blend ingredients.	DNA gives codes for assembling the needed protein.
Errand boy	Brings the instruction (recipe) from the computer room to the mixing area.	Messenger RNA from the nucleus to the cytoplasm bringing out the DNA code.
Stores Assistant	Reads instruction and collects all the ingredients to manufacture the drink.	Transfer RNA collects needed amino acids as per the code.
Assembly line	Brewing, filtering and flavouring area of the plant	Endoplasmic reticulum, where the proteins are assembled and completed.
Packaging group 1	Bottling the final product for local consumption.	Ribosomal RNA assembling the proteins used by the cell.
Reflection		
Conclusions	Was the analog clear and useful or confusing?	The analog seemed clear, useful, interesting and understandable. A few students requested for an electronic copy of the analogy picture. The students shared the differences between the analog and target with the class. They gave their own analogy for a cell. To confirm the students' understanding, their written opinions on the analog were collected and analysed for improvement.
Improvements	Refocus as above in light of outcomes.	The analogy will be refocused in the light of the above outcomes.

4.1.5 Preparation for the Pretest

The lesson on the structure and function of a cell was taught in the class before the analogy was introduced. The lesson began with a brief introduction followed by a few questions to find out the students' preconception on cells. It was found that the students were not exposed to this concept earlier. The lesson was developed with a diagram, drawn step by step, with the explanation pertaining to the details shown in the diagram. To make it more comprehensible for the students, a situation was created and explained along with the technical details. The students were shown a virus infecting a nasal epithelial cell positioned inside a nose drawn on the board. The epithelial cell was shown as a typical cell with all the cell organelles. Since the explanation started with 'how we catch cold', a real life situation, the students' attention was captured straightaway. This 'smart move' did induce a minor glitch in student understanding, which was not known until later and this has been explained in the analysis. Every cell organelle was named and its function was explained. Then the plant cells were taken up for discussion and learning. The non-living inclusions of cells were listed out and their functions and significance were described. The lesson on cells ended with eliciting the differences between an animal cell and a plant cell and recording the details.

An adapted version of the Two-Tier Diagnostic Instrument designed by Treagust (1985) to test the students' understanding of cells (refer to Appendix B 3) was administered on the following day, after the presentation of the analogy. The answer papers were collected for analysis.

4.2 Quantitative Analysis of the Results

4.2.1 Two-Tier Diagnostic Test

Two-tier questions were framed carefully to bring out the students' understanding and alternate conceptions. The questions had the ability to test all of the above and the students' higher order thinking; thus testing the effectiveness of presenting the scientific concepts incorporating an analogy using the FAR Guide. Two examples of the two-tier questions have been selected and their significance is elaborated here to show the effectiveness of the two-tier testing, consequently justifying the use of the FAR Guide to present an analogy.

Question 2: Why don't I see any cells in a piece of meat?

Answers:

1) Meat is made of cells, which are so small, that it is not visible to our naked eyes.
2) Meat is not made of cells
3) Meat is chunky and not divided into small units.

Reasons:

When I wrote this answer, my thought/s was/were:

a) Meat and cells are entirely different things and we can't find cells in meat.
b) There are cells in animals, not necessarily in a piece of meat.
c) The cells are there, but I am unable to see it with my naked eye.

The students tend to compartmentalise what they learn without integrating the information for thorough understanding and higher order thinking. It has been observed that quite a few students knew about cells, but unfortunately they found it difficult to correlate what they knew with real world situations. The original idea of this particular question came from a biology student in Year 11, who could not accept meat as a mass of different cells put together. Though a good percentage of students chose the correct answer and reason (87% and 84% respectively) in this cohort, 13% of the students held the alternate conceptions that 'Meat is not made of cells'; they supposed that 'There are cells in animals, they are not necessarily in meat'. This question brought out the students' knowledge and alternate conceptions relating to meat and cells.

The following question and answers brought out the students' knowledge on cell interaction and communication to coordinate body functions.

Question 7: How does the nucleus communicate with the rest of the organelles in the cell?

Answers:

1) The mitochondria send messages through the DNA molecules and control all the activities of the cell.

2) The DNA molecules in the nucleus give out coded messages by sending messenger RNA into the cytoplasm.

3) The ER membranes pass on the messages from the nucleus to the other organelles.

Reasons:

a) Mitochondrion is the powerhouse, which has the power to send messages to control all the activities.

b) The DNA has the instructions or codes for the messages, which control all the activities of the cell.

c) ER membranes are continuous tubes through which messages can pass easily to the organelles.

The DNA molecules were compared to the recipe for the soft drink stored in a computer and the templates coded for proteins coming from the DNA molecules were compared to the ingredients and blending instructions given in the recipe. This enhanced the understanding of the concept and enabled 92% of the cohort to choose the correct answer in the posttest; an increase of 34% from the pretest. Similarly, the correct reason was chosen by 76% of the students, which was an increase of 16% from the pretest. All the students who had held the alternate conception that 'Mitochondrion is the powerhouse, which has the power to send messages to control all the activities' changed their choice in the posttest after the presentation. Thus, all the questions in the two-tier test were designed cautiously to test the understanding of the concept and to bring out the alternate conceptions. The detailed analyses of the individual responses (Appendix B 4) indicate this phenomenon and hence, reveal the impact of the presented analogy using the FAR Guide on the understanding of the cell. The same two-tier diagnostic test was administered during the following science period, which was a day later. The students took the posttest without the prior knowledge of the correct answers. Cronbach alpha reliability measures for the pretest and posttest were 0.60 and 0.23, respectively. The posttest' low reliability is discussed in Chapter 8.

4.2.2 Statistical Analysis of the Diagnostic Test Results

Table 4.1: A comparison of students' pretest and posttest total scores on the teacher-constructed 'Cell –Structure and function' two-tier test using paired sample t-test statistic (n 38)

		Mean	Std Deviation	Std Error Mean	t value
Pair 1	TOTAL-pretest	5.39	2.11	0.34	3.39
	TOTAL_ posttest	6.34	1.6	0.26	

The pretest results showed an average of 61.0% correct answers and 53.7% for correct answers and correct reasons, where as the posttest results showed an average of 72.9%% and 63.5%, respectively which is an increase of 11.9% in the correct answers and 10.2% in the correct answers and reasons after the intervention. This seems to indicate that the students did benefit from the presentation of the concept incorporating the analogy as per the specification given in the FAR guide. The alternate conceptions held by the students showed a decrease of 3.79% after the intervention.

Table 4.2: The percentage of students who correctly answered the first tier and both tiers of the items in the teacher-constructed 'Cell Structure and Function' two-tier diagnostic test (N [38])

	'Cell Structure and Function' Pretest			**'Cell Structure and Function'** Posttest	
Question number	Percentage of students who correctly answered		Question number	Percentage of students who correctly answered	
	first tier	both tiers		first tier	both tiers
1	18	18	1	21	18
2	79	76	2	87	82
3	76	50	3	82	50
4	95	92	4	97	95
5	47	42	5	66	66
6	63	55	6	79	61
7	58	55	7	92	76
8	21	18	8	45	42
9	71	68	9	89	90
10	82	63	10	71	55
Mean	61.0	53.7	Mean	72.9	63.5

A paired-samples t-test was conducted to evaluate the effect of the instruction on students' total scores on the "Cell - Structure and Function" diagnostic test. There was a statistically significant increase from the pretest (M=5.39, SD=2.11) to the posttest [M=6.34, SD=1.60, t(37)=3.39, p<0.01]. The Cohen's d statistic of 0.51 indicated a medium effect size. The results included in Table 4.2, indicate that the students slightly improved their scores from pretest to posttest. The percentage of students who correctly answered the first tier and both tiers are shown in Table 4.2. The percentage of students' responses on most items is less when the two tiers are combined, compared to the first tier only. The percentage on both tiers showed improvement in the posttest.

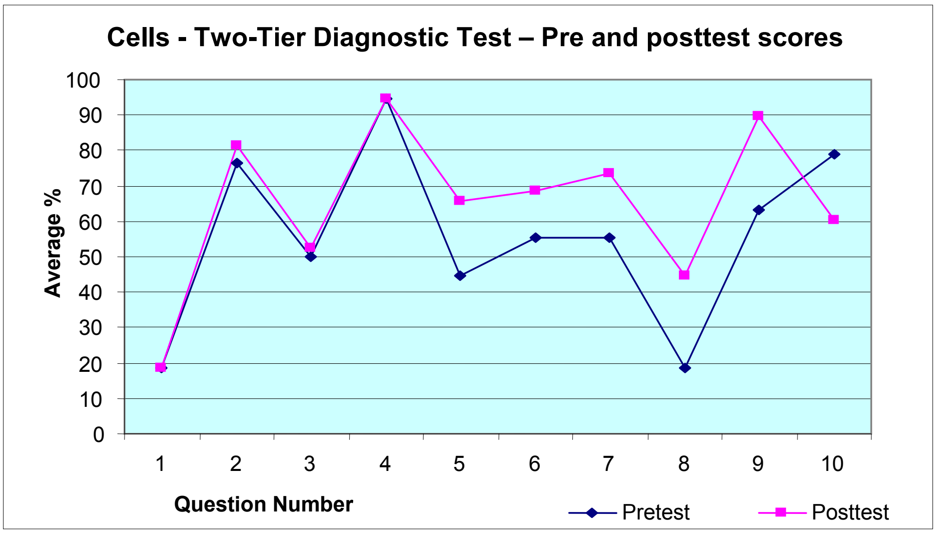


Figure 4.1: Average percentage correct scores on the two-tier diagnostic pretest and post test on the teacher-constructed 'Cell' diagnostic test (N [38])

4.2. 3 Analysis of Gender Differences in the Test Results

Repeated mixed between-within subjects analyses of variance were performed to identify any gender differences. Though the pretest-posttest means were significantly different [F(1, 36) = 9.78, p<0.01], there was no significant difference between the pretest and posttest means for males and females [F(1,36) = 0.15, p>0.05].

Table 4.3: Statistical analysis of gender differences in their performance (N[38])

Concept	Pretest Means		Pretest SD		Posttest Means		Posttest SD	
	Male	Female	Male	Female	Male	Female	Male	Female
Cell	5.22	5.67	2.54	1.23	6.35	6.33	1.53	1.76

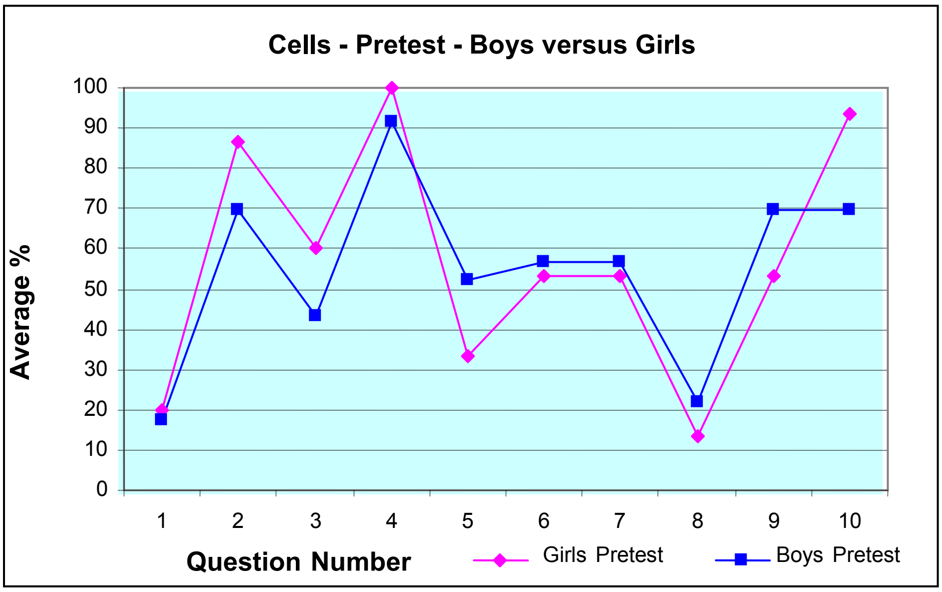


Figure 4.2: Average percentage correct scores on the two-tier diagnostic pretest on the teacher-constructed 'Cell' diagnostic test for boys and girls (N [38])

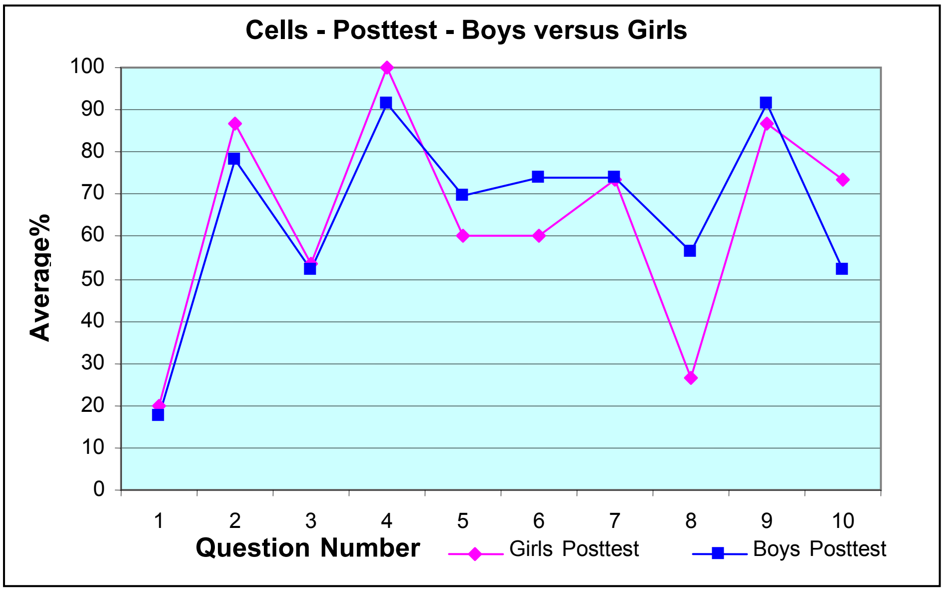


Figure 4.3: Average percentage correct scores on the two-tier diagnostic post test on the teacher-constructed 'Cell' diagnostic test for boys and girls (N[38])

4.3 Qualitative Analysis

This cohort was not taught about cells at primary school and they had no prior knowledge to construct the new knowledge given to them. As a result, when the topic was introduced, the students found it very difficult to comprehend what was taught. There was an atmosphere of negativity and lack of enthusiasm. The class didn't show any interest in learning about cells. Once the analogy was given, the students' outlook changed completely. Many of them participated actively. In fact, they were quite excited about being able to contribute to the analog-target mapping. Their reflective comments indicate this change.

4.3.1 Students' Reflective Comments on the Effectiveness of the Analogy

A few students' comments regarding the presentation of analogy using the FAR Guide:

Understanding:

'. . . cell organelles are like 'little people', each having his or her own job to do'. (Billy)

'Analogy made it seem more understandable and it was an interesting way to put it. If something I like comes up, I am all ears for. If it is something I don't like, I switch off". (Tekura)

'Analogy made my mind connect and focus more on what I was working on, rather than what the rest of the class was doing, so I wasn't as distracted. ' (Anonymous).

Analogy is great because it helps every one (including me) to understand what it is that they are working on. It is basically an example that every one can understand'. (Sarah)

'Yes, (analogy helped), that way, I can relate to it and see it in my own eyes. That way, instead of trying to figure out what a cell looks like, instead I can picture a factory'. (Hannah)

'Analogy did help, when I did not know about cell. But when I learnt about it, it is the same. I can use both ways'. (Lochlan)

4.3.2 Higher Order Thinking

Zohar and Dori (2003) summarised their understanding of Bloom's Taxonomy and Resnik's research findings (1987) and listed the following as the characteristics of higher order thinking:

> The term higher order thinking skills may also be used to delineate cognitive activities that are beyond the stage of understanding and lower level application according to Bloom's taxonomy (Bloom, 1956)…. Additional examples of cognitive activities that are classified as higher order include constructing arguments, asking research questions, making comparisons, solving non-algorithmic complex problems, dealing with controversies, and identifying hidden assumptions. Most of the classical scientific inquiry skills, such as formulating hypotheses, planning experiments, or drawing conclusions are also classified as higher order thinking skills. It is justified to group such varied cognitive activities into the same category of "higher order thinking" activities because despite the fact that they are so different from each other, they all follow the characteristics of higher order thinking according to Resnick. In addition, all of them would also be classified into stages that are beyond recall of information and comprehension according to Bloom's taxonomy.

In this study, the students were encouraged to generate and present their own analogies for the cell and a few questions were structured to elicit individual responses, which required higher order thinking. There was a class discussion on the student-generated analogies presented in Table 4.4. The majority of the students actively participated in the presentation and discussion with interest. Based on the findings of the above educators, could we assume that all the students who were successful in generating their own analogies for the cell and individual analogs for the organelles exercised their higher order thinking skills, when they generated their own analogies? It has to be admitted that there were a few students, who found it difficult to comprehend the complex nature of the cell even after the presentation of the teacher's analogy and many could not generate their own analogy for the concept. The students' comments and generated analogies were complementary to the quantitative data collected and indicate that the analogy presented using the FAR Guide was beneficial to many of the students in understanding the structure and function of cells.

Table 4.4: **Student generated analogs and corresponding targets**

Student generated analogies for the cell (Cara)	
Analog	Target
Oil/Cargo ship	Cell
Captain of the ship	Nucleus
Charts	DNA
1st mate	mRNA
Deck, Hull, Doors	Cell membrane
(Cara sailed from South Africa to Australia to become of a permanent resident).	
Student generated analogy for the cell (Hannah)	
Analog	Target
My house	Cell
All the dirt and rubblish	Cytoplasm
Walls and doors	Cell membrane
Lights	Chloroplast (if plant)
Power box	Mitochondria
Hall way	Endoplasmic Reticulum
Student-generated analogies for Mitochondria:	
Analog	Target
Solar Panel(Noelani) Power house (Lochlan) On and Off button to turn the power on (Tekura)	Mitochondria
Student-generated analogies for mRNA:	
Analog	Target
Post man (Sarah, Dlovan) Runner (Michelle) Bell boy (Nathan) Telephone (since it passes on messages) (Hannah) Messenger boy (Billy) Loud speaker (Philip)	mRNA
Student generated analogies for Nucleus	
Analog	Target
Mum (It looks the same because when I was a baby, my mum knew all the things that I had to do). Dlovan Boss (Billy) Brain (of the cell) Michelle Parent (Sarah)	Nucleus
Student-generated the following analogies for Lysosomes:	
Analog	Target
'Recyclery' (Abdul) Recycle bin (Anna) Garbage man (Billy)	Lysosomes

4.4 Summary of the Chapter

The research informed me that:

The students enjoy learning when they are offered visual analogies to simplify a scientific concept.

When students enter high school without the prior knowledge of certain scientific concepts, it is the responsibility of the teacher to lay a strong foundation for further construction, utilising all the available teaching tools; analogy could be one of them.

The students have difficulty in understanding the concept of cell as a structural and functional unit in living because of its microscopic size; therefore, the need to design a familiar analogy, which would make the concept tangible.

Many students see meat and cells as separate entities and much effort is needed to remove this misconception.

The students can easily construct alternative conceptions while the teacher aims at assisting in understanding. From the students' responses, it has been concluded that the students remembered that if a cell is 'programmed' to protect us from cold viruses, 'It does not allow us to die'. This situation resulted from the teacher's explanation of the structure and function of the cell organelles referring to an infected nasal epithelial cell by a cold virus and the way the cell and organelles react to protect the cell. This single event was used to bring out the functions of DNA, mRNA, tRNA, ribosomal RNA, Golgi bodies, endoplasmic reticulum, lysosomes and others before the pretest. The cell's ability to communicate to involve white blood cells to fight the viruses was also explained. This was done with the hope of teaching the concept holistically. Though the created situation drew their attention instantaneously and made a strong impact on understanding and memory, unfortunately, it also added to their imagination to conclude that the cells will not allow us to die! The teacher should exercise constant vigil to make sure such alternative conceptions do not creep in.

Chapter 5

Analogy 3 – Chromosomal Crossing Over - A Paper Craft

5.0 Introduction

This chapter begins with a brief description of the underlying rationale, which explains why the chromosomal crossing over was chosen as the next target and why this particular activity was designed to teach this concept to Year 12 biology students (Section 5.1). This is followed by a brief account of how the FAR Guide was adapted and used to present the concept without deviating from the requirements specified in the FAR Guide. The procedures during the Focus, Action and Reflection stages are also included in Section 5.1. The details of the two-tier diagnostic test results, which contributed to the quantitative data, analysis of the results and their statistical significance are shown for the whole group and based on gender (Section 5.2). The qualitative data collected from the observation and discussions during and after the activity, analog-target mapping sheet, reflective comments and their significance and the peer review are included in Section 5.3. The peer review contains two pre-service teachers' views and this has been added due to their relevance to the research undertaken.

The chapter links with Appendix C, consisting of the details of the cut and paste paper craft activity. The Appendix C begins with the diagrams of the three 'paper cut outs' showing the original 'chromosomes' on which the students had to mark the traits controlled by the corresponding genes and the resulting combinations after the swap (C.1 a, b, c) The next Section C.2 has the Far Guide adapted to suit the chosen analogy. Section C.3 and C.6 are two colourful worksheets used during the analog-target mapping, given in C.7. The next Section C. 4 includes the two-tier diagnostic test questions on the crossing over of chromosomes during meiosis and Section C.5 shows the analysis of the individual answers, which also shows the increase/decrease percent of the correct answers and alternate conceptions on the analogy. C.8 contains the questions asked to elicit the students' reflections and C.9 contains the graphs, which display the results of the pretest and posttest for the whole group and based on the gender. Section C.10 contains a few pictures taken during the activity. The frequency tables used in the statistical analysis of the results are added at the end (C. 10).

5.1 Methodology: Chromosomal Crossing Over - A Cut and Paste Paper Craft Activity

5.1.1 Rationale

Just like the atom, chromosomal crossing over is an abstract concept for students. It is not possible for them to visualise how chromosomes behave during the initial stages of meiosis to achieve a different gene combination in the resulting reproductive cells; hence it remains a mystery to many of them. It has been observed that despite the teacher's effort to explain this concept to the best of his/her ability, many are likely to find the concept and the underlying significance incomprehensible. The need to cut and swap segments gave me the idea of a paper craft activity (details in Appendix C. 1 - 3). Once this was decided, the rest fell into place like a jigsaw puzzle.

5.1.2 The Intervention Using the FAR Guide

It was required to create a simple analogy, which had the ability to unravel the mystery of the chromosomal twisting and breaking at certain points to create a relatively new chromosome with different gene combinations compared to the original one. It was decided to use a blue paper cut out to represent the paternal chromosome and pink to represent the maternal chromosome as per the accepted norm. Two chromosome-shaped pieces, a blue and pink, were given to each pair of students. The students were told to mark the various foci and write the traits controlled by the genes at these foci on the 'chromosomes'. Since the students worked in pairs, the interaction between the pairs assisted to clarify their own understanding of the concept and was further facilitated by the teacher's participation. Once the genes were marked, the students were asked to write the phenotype of the parents on the space given below the 'chromosome' (details in Appendix C. 1 a-c). This helped them to visualise the likelihood of the traits of the parents mentally and the traits, which are likely to be passed on to the next generation.

At this stage, an additional blue and pink 'chromosomes' were given to them. The students were asked to consider that the original chromosomes had duplicated and hence, were identical to the paternal and maternal chromosomes. The students copied the same traits at the same positions. Then, the students were asked to place the 'chromosomes' side by side and were asked to cut the juxtaposed pieces at random, swap those segments without changing their positions and glue them on the given sheet. After this, they were asked to write the traits showing the change in the 'chromosomes'. Every step was carefully planned and adopted as specified in the FAR Guide. To avoid confusion, the students were asked to cut and exchange segments between the middle two non-sister 'chromosomes' only. They were told that it was possible that both the pairs could exchange segments, if they were close to each other. They were also cautioned that not all the traits transferred from the parents to their offspring would show the corresponding traits since the gene expression is subjected to many other conditions. The students were told about Mendel's study on sweet peas and the various theories, which emerged as a result of the investigations carried out by many scientists based on Mendel's study. This refreshed the students' memory of what they had learnt in Year 10 and we discussed the Laws of Complete, Partial and Incomplete Dominance and the Law of Segregation. The students seemed to enjoy the activity and active participation was observed.

5.1.3 Sample

The sample chosen for this investigation on the effectiveness of using the FAR Guide to present the analogy for the chromosomal crossing over consisted of two successive batches of Year 12 students (2005 & 2006); a total of 23 students, consisting of 14 girls and 9 boys, aged between 16 and 19 years. The students were tested for their preconception on the crossing over of chromosomes. Although the students were introduced to the principles of genetics in Year 10, they had no idea of chromosomal crossing over and the significance of the resulting genetic diversity. Therefore, it was decided to teach the concept of the crossing over of chromosomes in great detail so that the students would acquire sufficient knowledge to understand the principles in genetics. Since the majority of the students were aiming at obtaining admission to universities for biology-related studies, it was imperative that they understood this complex concept at this stage of study.

5.1.4 Preparation for the Pretest

The process of meiotic cell division in the reproductive cells of animals was explained with labelled diagrams on the board. The various stages were named and the process of crossing over was explained using technical terms as needed. From their body language and answers to a few questions given to them to test their understanding, it was realized that they were unable to comprehend why and how the chromosomes behave in this manner and the related significance. Moreover, they had difficulty in understanding the scientific terms. To assist them in understanding, a colourful hand out was prepared and given to the students, which contained labelled diagrams and a few details of the process of crossing over. This sheet was given a title, 'An aid to understand crossing over' (given in Appendix C.3), hoping it would help the students to understand the process. The students worked together in groups of two and went through the hand-out. This was followed by a discussion. During the next lesson, the two-tier test on crossing over was given to the students. The answer sheets were collected for analysis.

5.1.5 The FAR Guide to Teach Crossing Over of Chromosomes During Meiosis

Focus		
Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept, 'Crossing Over of chromosomes' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a 'cut and paste' paper craft activity.
Action		
Likes	Discuss the features of analog and the science concept. Draw similarities between them.	The A4 paper represents the nucleus. The blue cut out and a similar pink cut with traits at different intervals marked by the students themselves represent the paternal and maternal chromosomes containing genes at different loci respectively. Sections cut between the loci, which were mutually exchanged and glued show the crossing over of homologous chromosomes and breaking apart after completing the process of crossing over. The resultant cut outs are carefully noted for the changes of genes and the corresponding traits in the recombination, which gives the idea of the consequent genetic variation in the resulting individual. (The details are given below)
Unlikes	Discuss where the analog is unlike the science concept	The analogy resembles the actual process of crossing over largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Similarities mapped out in detail		
ANALOG	*ANALOG - FEATURES*	*TARGET*
A 4 Paper	The background for the blue and pink cut outs.	Nucleus of the dividing reproductive cell, where chromosomes are present.
The blue and pink cut outs with labels.	Different chosen traits written by the students at different positions on the cut out. A list showing the traits written at the bottom of each cut out.	The inherited paternal and maternal chromosomes have genes at different loci, which control the traits shown in the resulting individual. The list shows the genes and the corresponding traits in the original chromosome
Placing another cut out of the same colour beside the cut outs.	Two identical cut outs showing the traits.	Homologous chromosomes have duplicated.
Lines drawn on the cut out	The lines the show the different segments and the genes present in those segments of the cut out.	Chiasmata are indicated at positions, where crossing over would occur between the non-sister chromatids.
Cuts are made at these points; the resulting segments are swapped between the adjacent blue and pink cut outs and glued.	Both the cut outs show a combination of two colours glued at the exact intervals.	The chromosomal segments have completed crossing over between non-sister chromatids.
Cut outs showing a new combination of blue and pink with written traits	The students make a list showing the new combination of traits on all the four cut outs.	After the crossing over, the resulting chromosomes differ from each other and this is the basis for genetic variation in individuals.
Reflection		
Conclusions	Was the analog clear and useful or confusing?	The analog seems to be clear and useful. The way the students were engrossed in the activity revealed their interest in the activity. During class discussion, student's preference for the colourful visual was revealed. The interesting comments on the analogy written by the students show that they thoroughly enjoyed the activity and grasped the concept it represented. Their knowledge was revealed when they brought out their own analogies and suggestions to eliminate the only 'dislike' in the analog-target relationship.
Improvements	Refocus as above in the light of outcomes	The analog will be refocused in the light of the above outcomes.

5.2 Quantitative Analysis of Results

5.2.1 Two- Tier Diagnostic Test

As with the other analogies, an adapted version of the two-tier diagnostic instrument designed by Treagust (1985) was prepared (given in Appendix C.4) and administered to test the students before and after the presentation of the analogy to find the students' understanding and alternative conceptions. The questions were framed carefully without omitting any of the details. The students took the posttest without the prior knowledge of the correct answers, which ensured reliability and validity of the results. The questions also had the ability to bring out the impact of the strategy on student understanding and hence the effectiveness of presenting the concept of crossing over incorporating an analogy using the FAR Guide. Two examples have been chosen from the two-tier question paper and their significance is elaborated here to show the effectiveness of the two-tier testing process.

Question 3: What is the meaning of 'crossing over' in this context?

Your answer:

4) The chromosomes moving across to the opposite poles during mitosis.
5) Certain chromosomes swapping segments.
6) Chromosomal number crossing over to 47 instead of 46.

The reason for choosing the above answer:

When I wrote this answer, my thought/s was/were:

d) The chromosomes move across to the opposite poles after duplication
e) The chromosomes divide and move across to make a total of 47 instead of 46 sometimes.
f) The chromosomes break and rejoin during cell division.

The above question tested the students' understanding of the meaning of the phrase, 'crossing over'. The posttest results revealed an increase of 43% (from 48% to 91%), which indicated that the students benefited by the analogy activity and 91% knew the meaning of the phrase. The remainder of the students, 9% of the cohort, held the misconception that crossing over means that the chromosomes moving across to the opposite poles during cell division. This indicates that these students were not sure of the answer and gave the literal meaning as the possible answer.

The following question was asked to find out whether the students knew the significance of the process of crossing over. None of them chose the correct answer in the pretest and the posttest average showed that 70% of the students chose this answer after the analogy activity, indicating that the analogy did help in the understanding of the concept. Only 48% of the students knew the correct reason and the other two alternate conceptions were held by 30% and 17% respectively.

Question 6: What is the purpose of crossing over during cell division?

Your answer:

1. To duplicate chromosomes.
2. To ensure the crossing over of mitotic spindles.
3. To ensure genetic diversity in the offspring.

The reason for choosing the above answer:

When I wrote this answer, my thought/s was/were:

a) Chromosomes get duplicated during cell division anyway.
b) The centrosome and mitotic spindles undergo a process of crossing over during cell division.
c) Genetic diversity is essential for the survival of the fittest.

Thus, all the questions in the two-tier test were set with a purpose, to bring out the understanding of the concept and alternate conceptions. The detailed analyses of the individual responses (Appendix C5) clearly show these details and help to recognize the impact of the presented analogy. The same two-tier diagnostic test was administered during the following science period, which was a day later. The answer papers were collected and analysed. The students took the posttest without the prior knowledge of the correct answers.

The overall two-tier diagnostic test results for crossing over showed that there was an increase of 34.78% (37.8%-72.6%) in the correct answers in the posttest and 16.43% (26.6%-49.9%) in the correct reasons. The alternate conceptions decreased by 10.42% after the presentation of the analogy as per the guidelines set in the FAR Guide. Cronbach alpha reliability measures for the pretest and posttest were 0.40 and 0.70, respectively. The low pretest reliability for the pretest is discussed in Chapter 8.

5.2.2 Statistical Analysis of Diagnostic Test Class Results

Table 5.1: Table 4.1: A comparison of students' pretest and posttest total scores on the teacher-constructed 'Crossing over' two-tier test using paired sample t-test statistic (n 23)

	Mean	Std Deviation	Std Error	t value
TOTAL _ pretest	2.91	1.78	0.37	4.60
TOTAL - posttest	5.04	2.36	0.49	

A paired-samples t-test was conducted to evaluate the effect of the instruction on students' scores on 'crossing over chromosomes'. The test showed an increase from the pretest (M=2.91, SD=1.78) to the posttest [M=5.04, SD=2.36, t(22)=4.6 p<0.01]. The Cohen's d statistic of 1.05 indicated a large effect size. As elaborated further in Table 5.2, students tended to improve their scores from pretest to posttest. The percentage of students who correctly answered the first tier and both tiers are shown in Table 5.2. The percentage of students' responses on most items is less when the two tiers are combined compared to the first tier only. Also, the percentage on both tiers shows improvement on the posttest. Details of the individual responses and explanations used in the quantitative analysis are given in Appendix A5.

Table 5.2: The percentage of students who correctly answered the first tier and both tiers of the items in the teacher-constructed 'Chromosomal Crossing Over' two-tier diagnostic test (N [23])

	'Chromosomal Crossing Over' Pretest			**'Chromosomal Crossing Over'** Posttest	
	Percentage of students who correctly answered			Percentage of students who correctly answered	
Question number	first tier	both tiers	Question number	first tier	both tiers
1	52	52	1	91	87
2	13	13	2	44	35
3	48	22	3	91	44
4	30	30	4	78	74
5	44	39	5	70	48
6	0	35	6	70	48
8	48	0	8	61	0
9	57	22	9	78	65
10	44	26	10	70	48
Mean	**37.3**	**26.6**	**Mean**	**72.6**	**49.9**

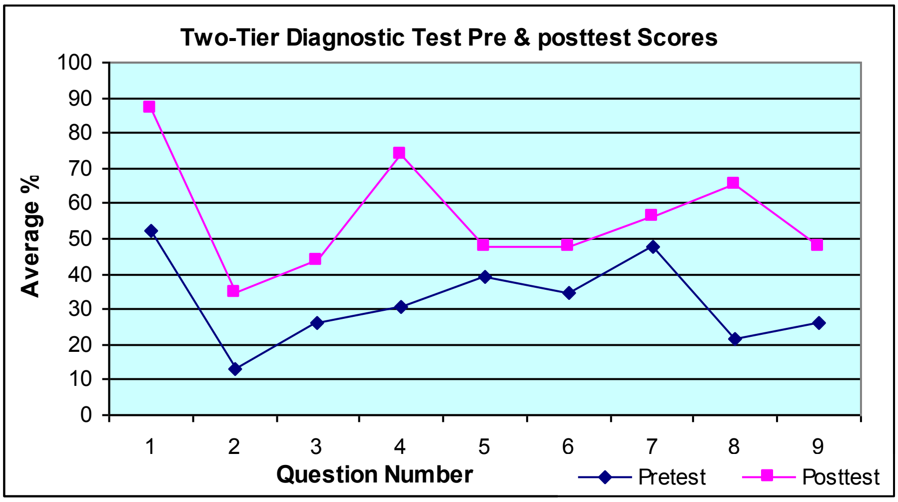


Figure 5.1: Average percentage correct pre and post test scores on the teacher-constructed two-tier diagnostic on 'Crossing Over' for boys and girls (N [23])

5.2.3 Analysis of Gender Differences in the Test Results

Table 5.3: Statistical analysis of gender differences in their performance (N[23])

Concept	Pretest Means		Pretest SD		Posttest Means		Posttest SD	
Crossing over	Male	Female	Male	Female	Male	Female	Male	Female
	2.56	3.14	1.51	1.96	4.67	5.29	2.36	2.43

The pretest-posttest means were significantly different for each of the boys ($t=2.96$, $p<.001$) and girls ($t = 3.06$, $p< .001$).

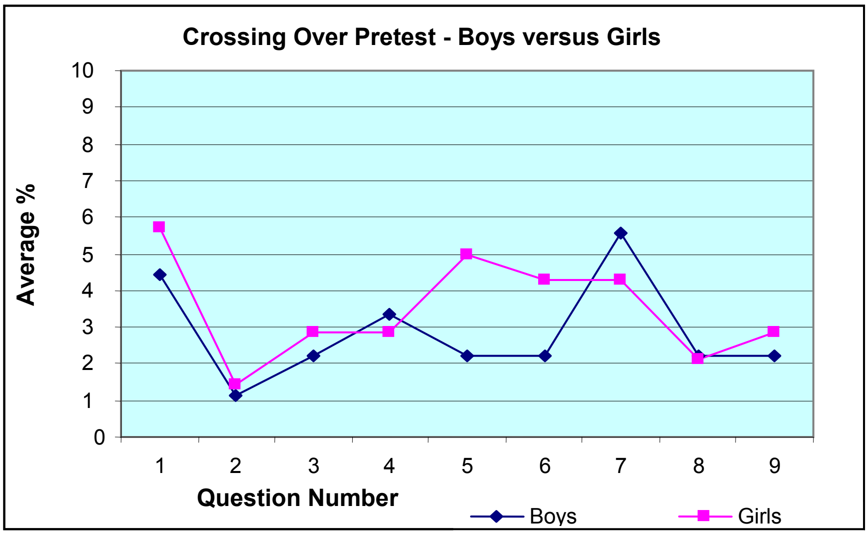


Figure 5.2: Average percentage correct pre test scores on the teacher-constructed two-tier diagnostic on 'Crossing Over' for boys versus girls (N **Error!**

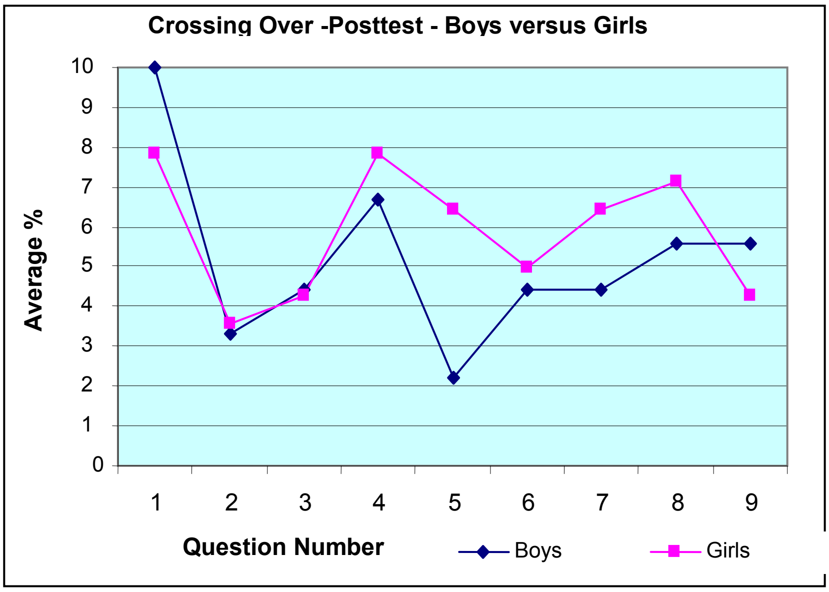


Figure 5.3: Average percentage correct post test scores on the teacher-constructed two-tier diagnostic on 'Crossing Over' for boys and girls (N [23])

5.3 Qualitative Analysis

The students' body language, interaction among themselves and with the teacher was treated as significant observations during and after the presentation of the analogy. The students' questions and responses during the sessions were considered as important to make conclusions. The reflective comments given by the students were carefully analysed to find whether they were complementary to the two-tier diagnostic test. A few, which reveal the students' opinion on the use of analogy in learning concepts, are given.

5.3.1 Students' Reflective Comments on the Effectiveness of the Paper Craft

Question: Did this activity help you to understand the principles involved in Chromosomal crossing over better than before?

All the students agreed that the analogy activity helped them to understand the principle of crossing over better. A few comments are included here:

'Yes, this activity helped to understand better than before'. (Anonymous)

'Yes, I actually understand it better because it was much easier to learn'. (Nelson)

'Yes, very much'. (Eleni)

'The activity was very useful'. (Bui)

'Yes, it definitely helped'. (Michelle)

'Yes, it helped a lot being able to do it myself'. (Elly)

'It helped, but the diagrams labelled helped, magic'. (Matt)

'Yes, somewhat'. (Beau)

'A little bit better; still a bit confusing to me'. (Claire)

'Yes, it did' (Homa)

Question: Explain giving reasons supporting your answer above.

'It was an actual activity that involved me individually to work it out'. (Eleni)

'The diagrams with different colours helped in understanding the difference in gametes'. (Matt)

The diagram was very helpful; you can understand very easy. The colours helped to understand the genes'. (Bui)

‘Rather than just listening and imagining the process, I did it and will remember better’. (Natalie)

‘I said it was easier to learn because the activity we did helps you, because you have to swap the pairs by yourself and also to complete the genetic diversity’. (Nelson)

‘It went in-depth and explained a few topics/concepts that were previously confusing’. (Beau)

‘Diagrams were helpful, the use of colours’. (Anonymous)

‘A whole heap of words is confusing, where as time is taken in an activity, which makes it easier to understand’. (Anonymous)

‘I was able to exchange genetic traits with my hands’. (Homa)

‘It helped a lot more, but the whole topic kind of confuses me’. (Claire)

‘I actually got to physically doing it. If I was wrong, I was corrected and teacher spoke through it with us’. (Lisa)

‘It was hands on, which made it easier to understand because we had to do each step and we had to understand each step before we went to the next one which was good’. (Michelle)

Question: Is this analogy-activity exactly like the chromosomal crossing over and when is it not like the chromosomal crossing over (known as the ‘breaking down’ of the given analogy)? Explain your answer.

‘Yes, it was mostly like the chromosomal crossing over. We just couldn’t show the twisting action of the process, but it was not important because we understood when and how it occurred’. (Eleni)

‘It is the exact same process but not every gene is used’. (Anonymous)

‘Yes, it is the same as the chromosomal crossing over because they cut them and cross them over’. (Nelson)

‘It is similar, but not identical’. (Anonymous)

‘The analogy couldn’t show the twisting part, otherwise it was great’. (Homa)

‘Yes, except for the actual twisting of the chromosomes, we said it happened, but didn’t actually do the step, but because we were talking about it we knew what it was’. (Michelle)

‘Yes, it was. Just there was no twisting with the chromosomes’. (Lisa)

‘The activity didn’t show the twisting part of the process’. (Matt)

Question: Can you think of any other analogy (real life example) of your own, which might help you understand the chromosomal crossing over better?

'Doing this activity with ribbon or string, instead of paper because then we can actually show the twisting, quite easily, and then we could cut it and see how it is evenly intertwined within each other non-sister chromosome'. (Michelle)
'Use string so you can twist and you can still paste it and cut to show the new combinations'. (Lisa)
'Another analogy can be arranging different beads in a necklace and exchanging the beads'. (Homa)
'Kebab sticks' (Claire)

The above comments indicate that the majority of the students felt that the analogy helped them to understand the process of crossing over and took them to a higher level in their thinking. The colour coding of blue and pink for paternal and maternal chromosomes, labelling the phenotypic traits on the paper to represent the genes and reading and writing the traits as seen on the 'chromosomes' prior to and after swapping the segments seemed to enhance student understanding. These comments complement the quantitative data and justify the Cohen's *d* statistic of 1.05 indicating a large effect size.

5.3.2 Peer Review

Ruth, one of the pre-service teachers was requested to give her opinion on the study. She seems to have focused on the two-tier questions and given the following view:

> Chromosomal Crossing Over:
> I find the questions in this test to be very 'challenging' for your average student.
> Higher Order Thinking is definitely necessary when responding to these questions. I find the questions on this test will separate and draw the line between your 'simple' and abstract/complex thinkers in the class; as previous understanding is necessary to answer these questions. However, many of the questions are related to each other, which may

make it easier if the student can pick up on it and at the same time, it may be more difficult with overlapping content matter.

Vidler, the other pre-service teacher gave his opinions as given below:

> The crossing over exam requires that for students to achieve a high result, they need to understand the processes and concepts clearly. This ensures that students' high results have understanding rather than content knowledge. The questions are clear, however, for the students who have a poor background in the area, some of the answers may be confusing due to the language. i.e. do not understand the answers, because the terminology is foreign to them. In relation to the misconceptions, it appears that the questions cover some general misconceptions that the students will have.

Though the pre-teachers reviews do not elaborate much about the research, they seem to suggest that the students were challenged by the questions and the questions were not deliberately made easy. These reviews also imply that the questions had the ability to test students' higher order thinking and were appropriately designed to test student-understanding precise to the point.

All the analogies presented as per the FAR Guide so far, including this 'cut and paste paper craft' seem to indicate that the FAR Guide, if appropriately applied, could offer a supportive platform on which a complex scientific concept could be laid out in a simple effective manner for students' better understanding.

5.4 Summary of Chapter

The research informed me that:

Students readily are motivated when activities like cut and paste paper craft are introduced to explain a difficult concept in teaching.

The teacher needs to facilitate step-by-step for the deep understanding of the concept.

The analogy should have maximum shared and minimum unshared attributes, if it were to yield good results.

Accepted norms take them to real world situations and play a vital role in student-understanding. (For example, blue for paternal and pink for maternal chromosomes.).

Team work offers assistance to overcome inadequacies in learners.

The students benefit from learning the technique of dissecting the scientific terms into base words, prefixes and suffixes and finding the meaning. Repeated use of the technique makes students curious to know more about the etymology of the scientific terms, which helps to add to their scientific vocabulary and knowledge, also results in long term retention. Teaching this technique at an early stage might benefit the students greatly at higher levels of study.

Chapter 6

Analogy 4 – Protein Synthesis - A Toy Assembly

6.0 Introduction

This chapter begins with a brief description of the underlying rationale, which explains why protein synthesis in cells was chosen as the next target (Section 6.1). This concept was presented incorporating a visual analogy of a toy factory to Year 12 biology students. The methodology, describes how the FAR Guide was adapted and used to present the concept, adopting all the steps specified in the FAR Guide. The procedure during the Focus, Action and Reflection stages and the associated teaching materials handed out to the students are also included in Section 6.1. The details of the two-tier diagnostic test results, which contributed to the quantitative data, analysis of these results and their statistical significance are shown for the whole group and based on the gender in 6.2. Section 6.3 contains the observation and discussions during and after the presentation of the analogy, analog-target mapping sheet and the reflective comments and their significance, which contributed the qualitative data. This section also contains the peer reviews from the two pre-service teachers.

Related to this chapter is Appendix D, consisting of the diagram of the analog showing the manufacturing process of a helicopter which relates to the process of protein synthesis (Section D.1), the FAR Guide (D.2) adapted to the process, two-tier diagnostic test questions (D.3), detailed analysis of individual answers and alternate conceptions, analog-target mapping worksheet (D.4), Graphs displaying the results of the pretest and posttest for the whole group and based on the gender, a questionnaire (D.5) to find the preconceptions on protein synthesis before the presentation of the analogy, analog and target mapping sheet, post- presentation reflection on protein synthesis (D.6) and finally, the frequency tables used in the statistical analysis of the results.

6.1 Methodology

6.1.1 Rationale -Protein Synthesis – A Toy Assembly

Protein synthesis is an abstract scientific concept for the students in biology. Since this is one of the vital processes taking place inside the cells, the students need to understand the process and retain in memory. It is almost impossible for students to visualise how the tiny organelles such the RNA particles work under the instruction of DNA in an amazing fashion to collect and assemble the ingredients to synthesise the specified proteins. Since this is an abstract concept, which can't be visualised, it has to be simplified and brought down to the intellectual level of young students. Hence, it was decided to choose this cell process as the next target. After giving much thought, a visual, which resembled the assembling unit of a toy factory, was created. (The analog diagram is given in Appendix D.1).

6.1.2 The Intervention Using the FAR Guide

The analogy diagram was designed in such a way that it resembled the assembly line in a toy factory to a large extent, which was easy for the students to understand. They were told that the computer in the factory stores the codes, list of parts and builder's manual needed to build a helicopter. Similarly the nucleus contains the DNA molecules, which generate the codes to collect and assemble the needed amino acids. Just as the helicopter is assembled as per the instruction, the proteins are assembled in cells as per the instruction passed on by the DNA through to ribosomal RNA via mRNA and tRNA. Any alteration in the code will produce a different product. It was observed that the students visualised a different picture of the entire process of protein synthesis after the presentation of the analogy. Every step was carefully planned and adopted as per the instructions given in the FAR Guide. (Details are given in 6.1.5).

6.1.3 Sample

The sample chosen for this investigation on the effectiveness of using the FAR Guide to present the analogy for crossing over consisted of two successive batches of Year 12 students (2005 & 2006). A total of 25, consisting of 15 girls and 10 boys, aged between

16 and 19 years. When the students were tested for their preconception on protein synthesis, it was found that they had no idea of this life process taking place in cells. Therefore, the students had to be given the structural and functional details of a cell before they were taught the process of protein synthesis.

6.1.4 Preparation for the Pretest

A labelled diagram of a typical animal cell was drawn on the board, the organelles were introduced and their functions in relation to the cell and organism were explained. This activity was followed by a video presentation on protein synthesis. The students were quiet most of the time which is an indication of confusion or inability to assimilate what was presented. They were encouraged to ask questions and clarify doubts. Perhaps, the understanding was so minimal that they did not even know what to ask. It was recognised in the past that crossing over and protein synthesis were the two concepts, which many of the students found incomprehensible to a large extent. As required, the students were given the two-tier diagnostic test after teaching the concept as described above. The answer sheets were collected and evaluated and this provided the data for analysis.

Focus		
Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Protein Synthesis' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept, though they are in year 12.
	Analog	The students are familiar with the chosen analog, which is a toy factory assembly unit.
Action		
Likes	Discuss the features of analog and the science concept and draw out similarities	The various steps in the synthesis of proteins could be compared to a factory where specific parts are assembled into a final product. (The details are given below).
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the actual process of protein synthesis largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.
Similarities mapped out in detail		

ANALOG	ANALOG - FEATURES	TARGET
A Toy Factory Assembly Unit	A toy helicopter is manufactured in this unit by assembling many parts together.	The Living Cell, where different kinds of proteins are synthesized by putting amino acids together.
Control room where the computer is kept. The computer has the design and details of the parts for the product, which is the toy helicopter.	The computer contains all the information, such as the size and colour of the parts, their codes and the instruction for assembling the parts, which will produce the toy helicopters in the end.	Nucleus where the DNA is placed; DNA contains the codes for all the amino acids, which when assembled as per the instruction will give the polypeptide chain (protein).
The controller brings the design and the assembling instructions out of the control room to the assembly area.	The print out contains all the details of the parts and the instructions to assemble them.	Messenger RNA bringing the codes for the amino acids out of the nucleus to the cytoplasm.
The controller gives the print out to the dispatcher so that he could collect the parts from the store.	The dispatcher gets the list of parts and instructions for the toy helicopter and collects the parts from the store.	Transfer RNA collects the amino acids from the cytoplasm as per the codes given by the Messenger RNA.
The assemblers (1, 2, 3, 4. . .) receive the parts from the dispatcher and assemble them according to the codes received.	The assemblers are placed along the assembly line. They receive the instructions and the specified parts and assemble them to get the final product, the toy helicopter.	The ribosomal RNA molecules receive the amino acids brought by the tRNA and assemble them into a polypeptide chain, which is the needed protein.

Reflection		
Conclusions	Was the analog clear and useful or confusing?	The analog seemed to be clear and useful. The students were quite excited when they found out that the process was not so complex as it once appeared, when it was initially taught; it is as simple as assembling a toy helicopter. The different proteins are formed when the assembly is changed. They found it very interesting when they realised that a toy helicopter could be holding a tail on top instead of the rotor, if the assembly went wrong. The same could happen to living, if the instructions for the assembly of proteins went wrong. Many brought out their own analogies along the same line. The example of haemophilia was discussed.
Improvements	Refocus as above in light of outcomes.	The analog will be refocused in the light of the above outcomes.

6.2 Quantitative Analysis of Results

6.2.1 Two-Tier Diagnostic Test

As it was done for the other analogies, an adapted version of the two-tier diagnostic instrument designed by Treagust (1985) was prepared (given in Appendix D.3) and was administered to the students before and after the presentation of the analogy. The questions were framed carefully to test the students' understanding of the concept without omitting any of the details, as well as to bring out the students' understanding and alternative conceptions. The students took the posttest without the prior knowledge of the correct answers and this ensured reliability and validity of the results. The questions had the ability to bring out the impact of the strategy on student understanding and hence, the effectiveness of presenting a scientific concept incorporating an analogy using the FAR Guide.

Two examples have been selected from the two-tier question paper and their significance is elaborated here to show the effectiveness of the two-tier testing process.

2. Where are the proteins produced in human body?

Your response:

1. The gland cells in human body produce proteins.
2. All the cells in human body synthesise proteins.
3. Liver produces all the proteins needed for human body.
4. Any other of your own ____

Your reason for the response:

a) Every living cell has the potential to produce proteins.
b) The gland cells alone can produce secretions.
c) Digestive system synthesises proteins.

Many students tend to assume that glands alone can produce substances for the body. They find it difficult to understand that every cell in an organism is capable of producing the needed substances. This question brought out the alternative conception that only the liver produces all the proteins for the body and the gland cells alone can produce secretions. Interestingly 40% dropped the conception that 'Digestive system synthesises proteins for the human body'.

The following question was added to find out whether the students had the understanding that the cells respond by synthesising specific proteins to a stimulus.

4. What initiates/starts the synthesis of proteins?

Your response:

1) Eating plenty of different kinds of proteins initiate the synthesis of proteins.
2) Need for a specific protein in a cell or body can initiate the process.
3) Lack of protein in the diet initiates the synthesis of proteins by the body.
4) Any other of your own ______________________________

Your reason for the response:

a) We add different kinds of proteins in our diet.
b) Proteins perform many vital tasks in a living organism
c) If we don't eat proteins, it is our body that produces proteins

The correct response was chosen by 68% of the students and this average was further increased to 72% after the presentation of the analogy. Eating plenty of proteins could initiate the synthesis of proteins is an alternate conception identified from the answers to this particular two-tier question.

All the questions in the two-tier test were set to bring out the understanding of the concept and alternate conceptions. The detailed analyses of the individual responses revealed these details (in Appendix D 4) and helped to recognize the impact of the presented analogy. The students took the posttest without the prior knowledge of the correct answers, a day after the presentation of the analogy. The answer papers were collected and analysed. The posttest results showed that there was an increase of 8.8% in the correct answers and 12.8% in the correct reasons. The alternative conceptions decreased by 5.14% after the presentation of the analogy, Cronbach alpha reliability measures for the pretest and posttest were 0.67 and 0.60, respectively.

6.2.2 *Statistical Analysis of the Diagnostic Test Results (Appendix D.8)*

Table 6.1: A comparison of students' pretest and posttest total scores on the teacher-constructed 'Protein synthesis' two-tier test using paired sample t-test statistic (n[25])

		Mean	Std. Deviation	Std. Error Mean	t value
Pair 1	TOTAL-pretest	4.24	2.51	.50	2.89
	TOTAL-posttest	5.48	2.24	.45	

The paired-samples t-test for 'Protein Synthesis' showed an increase from the pretest ($M=4.24$, $SD=2.50$) to the posttest [$M=5.48$, $SD=2.24$, $t(24)=2.89$, $p<0.01$] which was statistically significant. The Cohen's *d* statistic of 0.52 indicated a medium effect size. As elaborated further by each item shown in Table 6.2, the students tended to improve their scores from pretest to posttest.. An average of 42% scored for the answer plus reason in the pretest was enhanced by 12% after the intervention. This seems to indicate that the students benefited from the presentation of the concept incorporating the analogy as per the FAR guide. The incorrect answers less than and above 10% were classified as alternate conceptions. All the answers, which showed an exceptional increase or decrease, were analysed in detail. The analysis of the individual responses and explanations used in the quantitative analysis are given in Appendix D.4. The percentage of students who correctly answered the first tier and both tiers are shown in Table 6.2. The percentage of students' responses on most items is less when the two tiers are combined compared to the first tier only. Also the percentage on both tiers has improved on the posttest.

Table 6.2 The percentage of students who correctly answered the first tier and both tiers of the items in the teacher-constructed 'Protein Synthesis' two-tier diagnostic test (N [25])

Question number	'Protein Synthesis' Pretest: Percentage of students who correctly answered		Question number	'Protein Synthesis' Posttest: Percentage of students who correctly answered	
	first tier	both tiers		first tier	both tiers
1	56	48	1	80	76
2	64	44	2	60	56
3	48	48	3	76	64
4	68	52	4	72	64
5	40	36	5	68	60
6	60	56	6	76	72
7	40	36	7	52	44
8	60	32	8	72	60
9	40	24	9	40	24
10	72	44	10	40	20
Mean	**54.8**	**42.0**	**Mean**	**63.6**	**54.0**

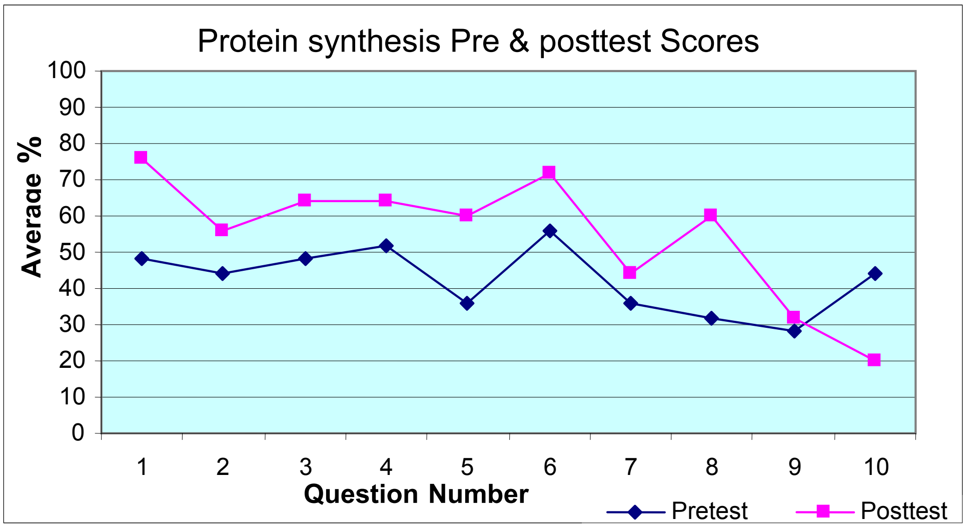


Figure 6.1: Average percentage correct scores on the two-tier diagnostic post test on the teacher-constructed 'Protein Synthesis' diagnostic test for boys and girls (N[25])

6.2.3 *Analysis of Gender Differences in the Test Results*

The raw score averages showed that the girls performed better than the boys both in the pre and posttest. The boys score increased by 11% after the presentation of the analogy and the girls score improved by 13%, showing that the girls were benefited by the analogy more than the boys.

Table 6.3: Statistical analysis of gender differences in their performance (n = 25)

Concept	Pretest Means		Pretest SD		Posttest Means		Posttest SD	
Protein synthesis	Male 3.40	Female 4.71	Male 2.12	Female 2.73	Male 4.50	Female 6.0	Male 2.22	Female 2.08

The pretest-posttest means were significantly different for each of the boys ($t=2.36$, $p<.05$) and girls ($t = 2.24$, $p< .05$).

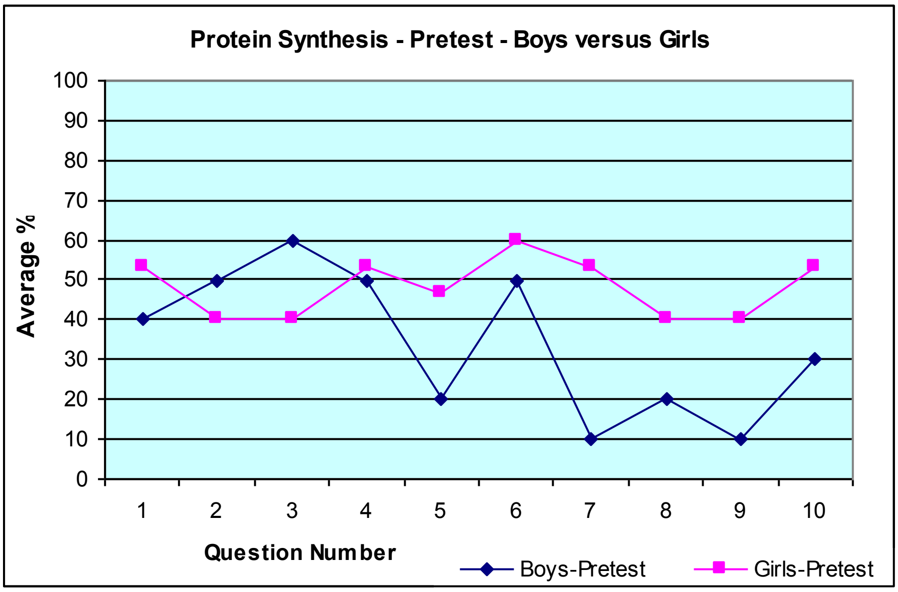


Figure 6.2: Average percentage correct scores on the two-tier diagnostic pretest on the teacher-constructed 'Protein Synthesis' diagnostic test for boys and girls (N [25])

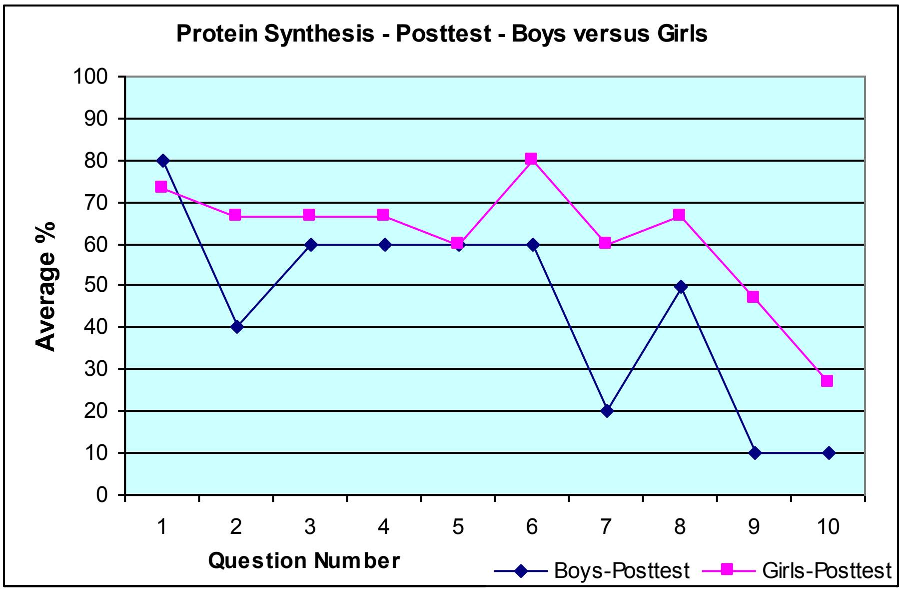


Figure 6.3: Average percentage correct scores on the two-tier diagnostic post test on the teacher-constructed 'Protein Synthesis' diagnostic test for boys and girls (N [25])

6.3 Qualitative Analysis

The students were observed very closely for what they displayed as body language. The interaction among the peers and with the teacher was noted and treated as significant during and after the presentation of the analogy. The students' questions and responses during and after the presentation were considered as important to make conclusions. The reflective comments given by the students were carefully analyzed to find whether they were complementary to the two-tier diagnostic test.

A few reflective comments, which reveal the students' opinion on learning scientific concepts using an analogy, are given below:

6.3.1 Students' Reflective Comments on the Effectiveness of the Analogy

Understanding and retention

'Analogy helps visualise the difficult concepts making the complicated steps involved simple and able to be memorised. The analogies did help me learn and understand the concepts about cells and proteins'. (Homa)

'Yes, my opinion on teaching with analogy to make certain scientific concepts easy is very good because the students would understand the message clearly. Yes, the analogies did help me learn more about cells and protein synthesis'. (Nelson)

'The diagrams of the processes make it easier to remember. Yeah, the analogies do help, I've just got to remember them'. (Emily)

'It was clear and useful as I can now refer to this and then can think of the scientific wording for the certain situation. I also learn well visually and with the diagram I can think back and picture it'. (Lisa)

'The teaching of analogy helped to make the process of protein synthesis more understandable'. (Beau)

'Referring to a coke factory or helicopter does help grasp some aspects of how cell works. Referring to things we are already familiar will give us something to refer to'. (Matt)

'Analog does make a certain scientific concepts easier to understand'. (Anonymous)

'Teaching with analogy makes concepts easy because it clearly and specifically informs you the key concept'. (Anonymous)

Higher Order Thinking - Student generated analogies for protein synthesis

- Making a cake (1) (Homa)
    - Recipe obtained from a book/computer (DNA)
    - Ingredients noted (mRNA)
    - Shopping for ingredients (tRNA)
    - Mixing the ingredients and baking the cake (ribosomal RNA)

- Baking a cake (2) - Almost the same explanation was given. (Lisa)

- Hamburger factory (1) (Beau)
    - 'Main computer prints out the recipe, people go about and take the recipe to the store, store worker collects the materials, people take parts/materials back to workers and the hamburger is produced'.

- Chocolate factory – sufficient explanation was not given. (Avan)

- A coke factory - No explanation was given. (Anonymous)

- 'The construction of many items, cars, bikes etc. but if you are looking for something individual the coke factory or the internals of a food/drink making company cane be more stimulating'. (Matt)

- 'Maybe a manufacturing factory of some sort like: food, drinks, vehicles, I'm not sure. But the examples used in class are good and clear'. (Sofia)

6.3.2 Peer Review

Ruth, one of the pre-service teachers gave her opinion on the study. She seems to have concentrated on the two-tier questions and given the following views:

Protein synthesis

- Generally speaking this is a topic many students have problems understanding.
- DNA synthesis is common abstract notion that has to be overcome through visual strategies such as analogies, videos, etc.
- Students tend to have problems "see"ing/visualizing the "BIG PICTURE" in many areas of biological science.
- For this test I think students would have a difficult time understanding
  # 5-10 if they do not have the background knowledge.
  i.e. 1-1: student may confuse protein consumed in food with protein @ a molecular level.
  1-2: if students previous conception of DNA structure is not clear they may have problems with this question; must relate proteins > DNA > Nucleus.
  2 a) should guide students through the question.

3. is a very good question. Those with developed critical thinking skills will be able to decipher the result of this question.

The other pre-service teacher, Vidler was very brief and wrote 'good' against the question numbers of the two-tier test, except for the question 5, which he felt that the choices given as answers showed ambiguity. All the analogies presented so far by adopting the FAR Guide, seem to indicate that the FAR Guide, if appropriately applied, could offer an effective means of simplifying highly complex scientific concepts such as protein synthesis to students' better understanding.

6.4 Summary of Chapter

This part of the research made me realise that:

Real world situations used as analogies have tremendous impact on student-learning.

The fear and apprehension created by the initial appearance of a complex concept get drastically reduced, when a simple analogy is introduced to make the unfamiliar, familiar.

The lack of understanding of scientific terms affects students' performance levels.

The two-tier diagnostic instrument is an effective tool to find out the students' lack of knowledge in the etymology of scientific terms, which affected their understanding and retention. (As a result of this study, a metalanguage program was included for the science students).

Chapter 7

Analogy 5 – Quantum Mechanical Model of an Atom - An Imaginary Computer Game

7.0 Introduction

This chapter begins with the rationale, which justifies the need to adopt specific strategies to teach the Quantum Mechanical Model of an atom in relation to the arrangement of electrons based on their energy levels. The methodology describes how the FAR Guide was adapted to present this concept incorporating the analogy without deviating from the requirements specified in the Guide. The procedures during the Focus, Action and Reflection stages and the associated teaching materials handed out to the students are included in Section 7.1. The details of the two-tier diagnostic test results, which contributed to the quantitative data, analysis of these results and their statistical significance are shown in Section 7.2 for the whole group and based on their gender. A set of review questions was prepared to get the students' comments. Since the students were in Year 11 at the time, the demand to complete the topics in chemistry at the end of the year, revision before the final assessments and other needs did not allow much time with the students. The questions to elicit student-reflection on the analogy were given to a few students who were available and these comments have been added. The qualitative data collected from the analog-target mapping sheet, class observation and discussions, a few reflective comments and their significance are shown in Section 7.3. Unfortunately, the pre-service teachers were unable to provide any suggestions or comments for this particular analogy since they were not familiar with the concept.

This chapter links with Appendix E, consisting of the slides showing the animated analogy of the Quantum Mechanical Model, which includes the analog-target mapping (E.1), the added slides to improve the content of the analogy after reflection (E.2), the FAR Guide adapted to the concept (E.3), two-tier diagnostic test questions and answers (E.4), detailed analysis of individual answers and alternate conceptions (E.5), Graphs which display the results of the pretest and posttest for the whole group and based on the gender (E.6), a questionnaire to elicit the students' reflective comments on the analogy and its effectiveness (E.7) and finally, the frequency tables (E.8). In addition, the

Power Point presentation of the original analogy and the improved version of the same are added at the end (E.9 & E.10).

7.1 Methodology

7.1.1 Rationale - The Quantum Model-An Imaginary Computer Game

Just like atoms and cells, the Quantum Mechanical Model is a highly complex concept in Chemistry. The students in Year 11 generally struggle to assimilate this concept, which gave the incentive to choose the Quantum Mechanical Model of the atom as the next target. (The analog diagram used in the presentation is given in Appendix E.1 and the added slides to improve the analogy after the posttest are shown in Appendix E.2).

7.1.2 The Intervention Using the FAR Guide

The need to make the complexity of the Quantum Mechanical Model simple required a lot of time to create an analogy, which would be appropriate and interesting to the students. The blank faces witnessed during the lesson when this concept was taught gave the indication that this concept had to be simplified for understanding. It would be considered as an advantage if the analogy drew attention and gained active participation. Therefore, an imaginary computer game was planned after a lot of speculation. In the absence of the required technical skill to program software to make this a reality, it was decided to settle for an imaginary situation. A Power Point presentation of the analogy contained most of the components correlating to the Quantum Mechanical Model of an atom. After the 'Reflection' stage, a few slides had to be added to include the names and contributions of a few scientists to the analogy to help students to remember the rules related to the concept. The FAR Guide was fully adopted. (Details are in Appendix E.3)

7.1.3 Sample

The sample chosen for this investigation to present the analogy on the Quantum Model consisted of two successive batches of Year 11 students (2005 & 2006). A total of 22, consisting of 12 girls and 10 boys, aged between 16 and 19. Since most of the students had the expectation of continuing tertiary studies in chemistry, they were given all the required fundamental details of the concept as stipulated in the Schools' Work Program.

7.1.4 Preparation for the Pretest

The lesson on the Quantum Mechanical Model was taught before the analogy was presented. After the introduction of the topic, a few questions were asked to find out the students' preconceptual knowledge on the Model. They were not exposed to this concept earlier.

The lesson was developed with a diagram of an atom, having a nucleus in the centre, surrounded by dotted concentric circles showing the energy levels, drawn step by step with the explanation pertaining to the details shown in the diagram. It was not difficult to perceive the disinterest in the students due the incomprehensible factual details given to them. The lesson had to be paused and they were given time to read their text about the Model and peruse the diagrams. Their doubts were clarified as and when raised. An adapted version of the two-tier diagnostic instrument to test the students' understanding of the Quantum Model (given in Appendix E.4) was administered on the following day and the papers were collected for analysis.

7.1.5 The FAR Guide to Teach the Analogy for Electron Configuration

Focus		
Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept, 'Electron Configuration' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a power point presentation of a tree with lateral branches, where birds take up positions on the branches at various levels.
Action		
Likes	Discuss the features of analog and the science concept. Draw similarities between them.	The tree is represents an atom and the lateral branches are orbits showing the various energy levels and orbitals. Each branch is named starting with the first letter of the corresponding orbital. For e.g. 's' orbital corresponds to the 'Slow' branch, 'p' to 'Power' branch and 'd' to 'Dart' branch.
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the atom and electron configuration largely. There will be a discussion in the class and the students will be encouraged to raise the similarities and dissimilarities, discuss and make conclusions.
Similarities mapped out in detail		
ANALOG	***ANALOG -FEATURES***	***TARGET***
The branches	The lines of different colours, specific for a particular branch. e.g. 1st branch is brown in colour, 2nd is purple and so on	The quantum number n1, n2 and so on
Cage	A blue box housing a pair of birds inside	An orbital with a pair of electrons
Slow branch	The lowest lateral branch of a main branch called 'slow' (1s/2s/3s,etc)	's' level
Power branch	The branch above the lowest branch of a main branch called 'power' (2p/3p, etc)	'p' level
Dart branch	The branch above the 'power' branch called 'dart' (4d/5d, etc)	'd' level
Fastest branch	The highest lateral branch of a main branch called 'fastest' (4f, 5f, etc)	'f' level
Bird	Flapping its wings inside the cage.	Electron spinning in an orbital
A pair of birds	Two birds flapping its wings inside the cage.	Two electrons with lowest energy at lowest orbital -Aufbau principle
Single bird in a cage	Flapping its wings inside the cage.	Electron with same energy and opposite spin - Hund's rule
Presumption that the birds spin vertically in opposite direction	Two birds flapping its wings inside the cage.	Two electrons with different Quantum number together -Pauli's exclusion principle
Reflection		
Conclusions	Was the analog clear and useful or confusing?	The students were quite excited about the power point presentation of the imaginary computer game. The discussion revealed that they were able to understand better with the analogy. Did they mean it? It is a very difficult concept to grasp? One student wanted a copy of the animation and he said that he 'loved' it! Will it help them to answer the application questions? The scientists will be subtly included in the presentation next time to help remember the rules.
Improvement	Refocus light of outcomes	The analog will be refocused in the light of the above outcomes.

7.2 Quantitative Analysis of the Results

7.2.1 Two-Tier Diagnostic Test

The two-tier questions were framed carefully to bring out the students' understanding and alternative conceptions prior to and after the presentation of the analogy. The questions had the ability to test all of the above and the students' higher order thinking; thus testing the effectiveness of presenting the scientific concepts incorporating an analogy using the FAR Guide. Two examples have been chosen from the two-tier questions on Quantum Mechanical Model and the significance in relation to finding out student-understanding and alternative conceptions has been explained. The result also shows the effectiveness of the two-tier testing for understanding and using the FAR Guide to present an analogy to teach complex scientific concepts.

Question 1: Can the positively charged protons pull the negative electrons towards the nucleus and cause a collapse of the atom?

Answer:

1. Yes
2. No
3. I am not sure
4. Any other or your own answer: ____

The reason for choosing the above answer:

When I wrote this answer, my thought/s were:

a) Oppositely charged particles attract each other.
b) The electrons have fixed energy to keep them at their energy levels.
c) When the proton number is greater, the electrons would be drawn into the positive nucleus.
d) Any other reason for your answer: ______________________________________

This question was included to test the basic knowledge and the students' ability to use higher order thinking skills. There is no explicit feature in the analogy, which gives a direct hint or reference to this particular answer. The students were expected to think and rationalise based on the structure of an atom and arrive at the correct answer. If they were correct in their thinking, they would pick the right reason straightaway for the phenomenon given in the question. If not, the two-tier testing would have revealed the students' alternate conceptions to a large extent.

Question 7: What is the criterion that governs the filling of atomic orbitals by electrons, according to Aufbau principle?

Answer:

1) Electrons with the highest energy enter the orbitals of lowest energy at first
2) Electrons with the lowest energy enter the orbitals of lowest energy at first
3) Electrons with the lowest energy enter the orbitals of highest energy at first
4) Any other or your own answer: ______________________________

The reason for choosing the above answer:

When I wrote this answer, my thought/s was/were:

a) Electrons with the highest energy shoots out to occupy the s orbital
b) Electrons with the lowest energy enters the s orbital at first
e) Electrons entering the s orbital has nothing to do with the energy level
d) Any other reason for your answer: ______________________________

Since the requirement of the syllabus is that the students know and remember the principles and rules governing the phenomenon, the names of the associated scientists were needed to enhance student understanding and retention. It was unfortunate that this was not thought about when the analogy was created at first. It was only after the posttest and reflection, the idea to incorporate the names of the scientists and their contributions was realized. This awareness led to the revision of the analogy. The revised analogy has been included in Appendix E.2. This revised analog was shown to the students after the posttest review and was well received. Since this was done after their posttest, the posttest average was not affected. Cronbach alpha reliability measures for the pretest and posttest were 0.68 and 0.72, respectively.

7.2.2 Statistical Analysis of the Diagnostic Test Results

Table 7.1: A comparison of students' pretest and posttest total scores on the teacher-constructed 'Quantum Mechanical Model' two-tier test using paired sample t-test statistic (n [22])

		Mean	Std. Deviation	Std. Error Mean	t value
Pair 1	TOTAL-pretest	4.36	2.40	0.51	
	TOTAL-posttest	5.41	2.60	0.55	2.33

A paired-samples t-test was conducted to evaluate the effect of the instruction on students' total scores in the administered diagnostic test on the Quantum Mechanical Model of the atom. There was a statistically significant increase from the pretest (M=4.36, SD=2.40) to the posttest [M=5.41, SD=2.59, t(21)=2.33, $p<0.01$]. The Cohen's *d* statistic of 0.42 indicated a medium effect size.

From the observations, conversations with the students and two-tier test scores, it was concluded that of all the five chosen concepts, the Quantum Mechanical Model of an atom was the most difficult abstract concept for the students to comprehend and visualise mentally. Yet the two-tier class test scores indicated that the posttest average was 9.5% more than the pretest average. The percentage of students who correctly answered the first tier and both tiers are shown in Table 7.2. The percentage of students' responses on most items is less when the two tiers are combined compared to the first tier only. Also the percentage on both tiers has improved on the posttest. Details of the quantitative analysis and explanations are given in Appendix E7.

Table 7.2: The percentage of students who correctly answered the first tier and both tiers of the items in the teacher-constructed 'Electronic Configuration' two-tier diagnostic test (N [22])

'Electronic Configuration' Pretest			'Electronic Configuration' Posttest		
Question number	Percentage of students who correctly answered: first tier	both tiers	Question number	Percentage of students who correctly answered: first tier	both tiers
1	55	46	1	77	68
2	59	27	2	77	32
3	77	68	3	86	73
4	27	14	4	36	14
5	64	41	5	68	50
6	78	64	6	86	82
7	46	41	7	68	64
8	68	68	8	59	59
9	64	14	9	55	27
10	59	50	10	50	50
11	18	0	11	32	9
Mean	61.5	43.3	Mean	69.4	52.8

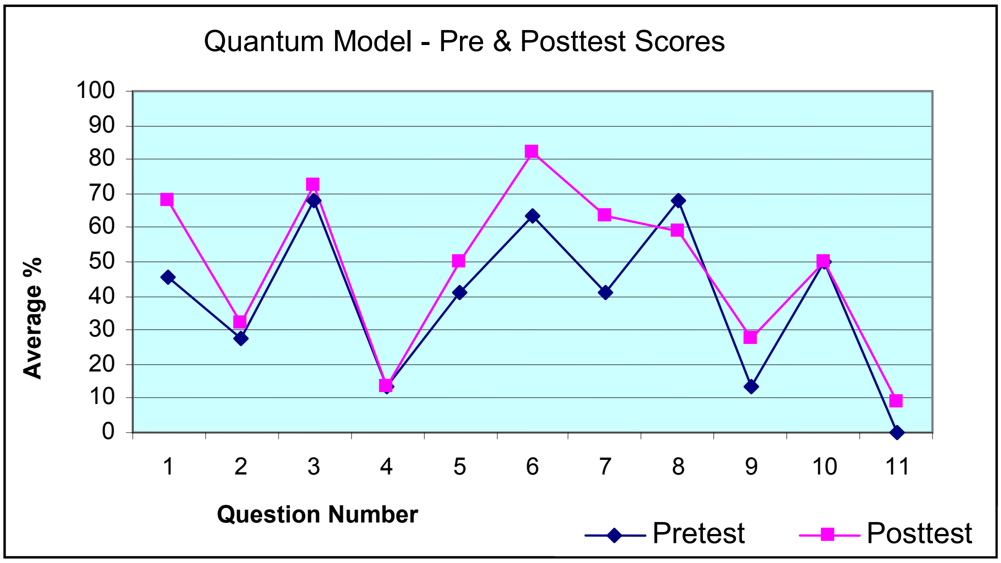


Figure 7.1: Average percentage correct scores on the two-tier diagnostic pretest and post test on the teacher-constructed 'Quantum Mechanical Model of an Atom -Electron Configuration' diagnostic test (N [22])

7.2.3 Analysis of Gender Differences in the Test Results

Table 7.3: Statistical analysis of gender differences in their performance (N[22])

Concept	Pretest Means		Pretest SD		Posttest Means		Posttest SD	
	Male	Female	Male	Female	Male	Female	Male	Female
The Quantum Model	4.10	4.58	2.96	1.93	5.80	5.08	2.57	2.68

The pretest-posttest means were significantly different for the boys ($t=2.19$, $p<.05$) but not for the girls ($t = 0.62$ $p> .05$). These results indicate that the boys benefited more than the girls after the analogy was introduced.

The Quantum Mechanical Model of an Atom (Electronic Configuration)

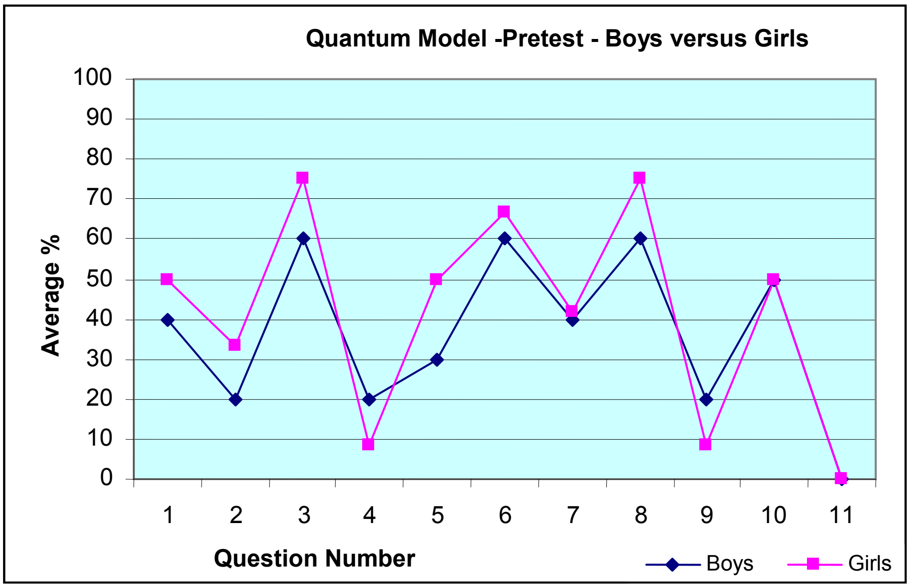


Figure 7.2: Average percentage correct scores on the two-tier diagnostic pretest on the teacher-constructed 'Quantum Mechanical Model of an Atom -Electron Configuration' diagnostic test for boys and girls (N [22])

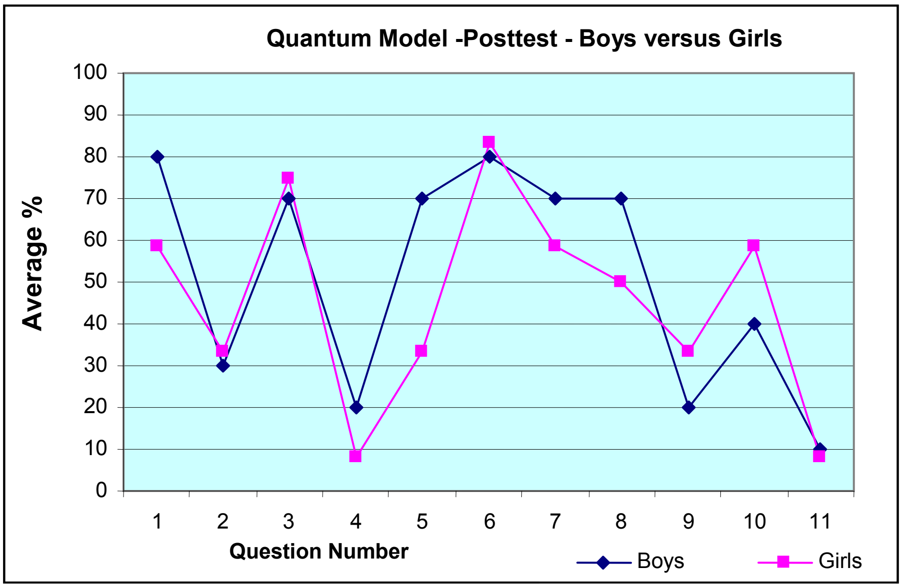


Figure 7.3: Average percentage correct scores on the two-tier diagnostic post test on the teacher-constructed 'Quantum Mechanical Model of an Atom -Electron Configuration' diagnostic test for boys and girls (N [22])

7.3 Qualitative Analysis

Due to lack of time, the questions to bring out the reflection on the analogy were given to a limited number of students, who were picked at random after the analogy was presented. Only the relevant reflective comments of the students are compiled here to show the understanding of the concept and the perception of the students on teaching complex concepts using analogies.

7.3.1 Students' Reflective Comments on the Imaginary Computer Game

Understanding and Retention:

'I remember (the structure of the atom) by the analogy and I am a visual learner'. (Azhee)

(This meant that before the 'Preparation for the pretest', the analogy should have been given to them)

'It helped me to understand the concept but it was shown after we were taught the electron configuration. So it was harder to grasp. I think if you show the students the tree diagram first, it will help them'. (Ayan)

'Yes, the analogy shows the position of electrons and it will be easy to remember because my brain takes information by the way of pictures. Visuals should be shown (Ahmed)

Despite the complex and abstract nature of the Quantum Mechanical Model of Electron Configuration it was concluded from the posttest scores that the analogy did help to enhance their understanding of the concept.

7.4 Summary of the Chapter

This part of the research informed me that:
There are many abstract scientific concepts, which cannot be understood by an average student in a class. It has to be made simple for understanding and this could be achieved by designing and incorporating a suitable analogy,

If that is the case, it is crucial to create an analogy, which has maximum shared attributes and minimum unshared characteristics.

The analogy has to be presented by adopting a systematic approach, and the strategy should allow the teacher the flexibility to reconsider the content of the analogy for review and revision even after the presentation to make it effective

A structured approach like the FAR Guide enables a teacher and students reflect upon teaching and learning after the analogy is presented and makes provisions to add remedial measures to enhance student–understanding.

When the unsuitability of the analog is recognised or need for addition of material is realised either after the presentation or during 'Reflection' (of the FAR Guide), remedial measures should be put in to minimise the ill effects and maximise the benefits.

All the five analogies presented support the fact that the FAR Guide, if adopted and implemented as per the guidelines given, could prove to be an effective teaching strategy and enhance students' achievement levels.

Chapter 8

Conclusions, Implications, Limitations and Future Directives

8.0 Introduction

This chapter is an amalgamation of what was perceived as a valid outcome based on the triangulated data obtained from the qualitative and quantitative research on presenting abstract and complex scientific concepts to students by incorporating an analogy using the FAR Guide. The goal of this research was to find an effective teaching tool, which has the potential to simplify complex scientific concepts for students' deep understanding. Grotzer (1996) in her review on 'Cognitive issues that affect math and science learning' recommends that educators should:

- teach for deep understanding,
- use strategies to help students transfer understandings,
- seek out the most generative topics for in-depth exploration,
- teach 'finding out' skills to help students learn throughout their lives.

The research informed that analogies not only simplify difficult concepts by bringing them down to students' level of understanding to compare on familiar grounds, but also transfer understandings to new situations, eventually leading to in-depth exploration, enabling a student to be a lifelong learner. The analogies focussed on meaningful patterns related to structure and purpose due to the mapping of analog-target relationship in great detail, which reduced or minimised alternative frameworks resulting in more connected information for long term retention; thus equipping a learner to apply the information to future problem solving. This chapter presents an overview of the research findings (section 8.1), the implications of the research (section 8.2), limitations of the research (section 8.3) and suggestions for future directions (section 8.4). The chapter ends with concluding comments (section 8.5).

8.1 Overview of the Research

Purpose of the study

To investigate the effectiveness of using the FAR guide to present analogies to teach and learn scientific concepts.

Objective 1: To investigate whether the chosen analogies have the potential to enhance student understanding of science concepts.

Research questions:

1a. What are the analogies that will correspond with the listed concepts and favour transfer?

The research looked at the analogies and analysed them for their merits in bringing about a better understanding of scientific concepts; consequently, their effect on student understanding and a means of enhancing the quality of science education.

It was apparent from the posttest results and the students' reflective comments that the analogs closely resembled the targets with maximum shared and minimum unshared attributes, had a positive impact on student learning and favoured meaningful transfer. The research showed that analogies can enhance thinking and not be a substitute for thinking (Holyoak & Thagard, 1995).

1b. What are the features in the analog that will make the target easier to grasp?

The research indicated that an analogy, if presented as a colourful and attractive visual representation of an easy-to-relate familiar situation from the students' world, would capture students' attention readily. The presence of pictures is an aid to understanding. Pictorial analogies may be presented by the teacher to highlight the desired attributes of a selected analog. This visualisation reduces the likelihood that students are not sufficiently familiar with the analog. In practice, most pictorial analogies are accompanied by some verbal explanation and should be referred to as pictorial-verbal analogies (Treagust, 1993). The research revealed that once the pictorial-verbal analogy caught the attention of the students, it became much easier to get active participation and involvement, favouring easy, effective and meaningful transfer for deep understanding and further construction. The students' reflective comments included in chapters 3-7 revealed the extent of the impact of the analogy on student-learning at a cognitive level. Moreover, the requests from students to own a digital copy of the analog affirmed the positive effect of the visual representations of the analogs on the students. The analysis of the posttest results revealed that all the analogies were beneficial; of these, the cut and paste paper craft analogy in Chapter 5 brought about the most favourable conceptual change. This particular analogy activity, which closely resembled the process of crossing over to a large extent, makes one wonder whether the excellent result in the posttest was due to the high degree of similarity between the analog and target.

> Whether an analogy is a good one depends largely on whether it achieves its purpose. And whether it achieves its purpose depends on the structural relations between source and target, for example, on whether the casually relevant features of the target have been mapped on to features of the source. If an analogy is successful learning can occur in the form of abstracting from source and target a general schema which captures the patterns of relational structure most relevant to the purpose of analogy (Hitchhock, 1996, p. 303-304).

The research indicated that an analogy linked with existing norms, which are familiar, capture students' interest and helps to apply the knowledge to the target. It revealed that the colours of the cut outs (chromosomes) enhanced their understanding by connecting the blue to paternal and pink to maternal chromosomes and the involved writing on the chromosomes to show the parental genes and inherited genes of the offspring made it easy to understand the contribution from the parents to the offspring and hence, the significance of the process of crossing over. The reflective comments in chapter 5 support this line of reasoning: The implication here is that a teacher should strive to design or acquire an analogy by linking all the possible experiences the students might have had in real world situations. Such an analogy facilitates effective concept development and achieves improved understanding of the concept.

1c. Do the analogies play a significant role in promoting understanding of the target?

The difference in the pre and post two-tier test scores and students' post-reflective comments indicated that the analogies did act as stepping stones to enable inductive transfer resulting in the comprehension of the analog-target relationship and thus, achieving the purpose of using analogies. The students' reflective statements given in every chapter support the view that analogies did help in understanding the difficult and abstract concepts presented to them. This result indicates that a teacher should include appropriate analogies in teaching to make a scientific complex concept simple. Analogies and models are excellent teaching and learning tools (Harrison, 2008).

Objective 2: To investigate whether the analogies have the potential to reduce incidence of alternative conceptions.

2a. What are the common alternative conceptions about the chosen concepts in students?

The research indicated that the invisible nature of the atom, microscopic size of cells, abstract nature of the Quantum Model and complexity of the concept itself, make it very difficult for the students to understand and connect the structure and processes. Despite the analogy given to them, it was found that many students held alternative conceptions until the posttest review. These alternative conceptions were clarified during the posttest review; yet, a few students might be still holding them, perhaps will continue to hold them until these concepts are revisited at a higher level of study. A similar finding was reported by Calik, Ayas and Coll (2009) who investigated the use of an analogy activity to effect conceptual change in their students on the aspects of solution chemistry. They reported that there was some evidence of students retaining alternative conceptions even after the intervention.

The research also indicated that the students had difficulty in approximating the size of cells in general, which is not crucial in understanding the cell processes, but needed to relate to the concepts concerning the anatomy and physiology of living organisms. The students seemed to have difficulty accepting plants as living organisms. Many failed to comprehend the role played by DNA and RNA in a cell and that all the cells are able to synthesise proteins to communicate with each other. It was identified that the Quantum Model of an Atom is abstract and highly complex for many of the students of chemistry; also the scientific terminology associated with the concept. The majority of the students lack the ability to remember the rules and associate the rules with the scientist who formulated them. Since the presentation of the analogy using the FAR Guide was the adopted procedure, and the two-tier testing being the diagnostic instrument, alternative conceptions were effectively identified from the pre and posttest answers and reasons, and from the reflective comments obtained during reflection in class. These findings provided the direction to plan the remedial work to include the rules and the scientists. This suggests that it is ideal to present an analogy using a systematic approach such as the FAR Guide and the use of diagnostic instruments such as the two-tier testing to bring out the effect of analogy on student-understanding and alternative conceptions, which informs the teacher the need to apply immediate remedial measures or consider in future implementation.

The research informed that the students have difficulty in comprehending the meaning of the scientific terms because of their limited or no knowledge of their Greek or Latin origin. This deficiency led to restricted use of scientific terms, generated uncertainty and hesitation to choose the correct answers, created alternative conceptions, affected the ability to apply the term to new situations and hindered students' long-term retention. The students tended to mix up the meaning of prefixes and gave incorrect explanations due to this limitation (hypo and hyper, homo and hetero, etc.). This situation gave the teacher-researcher the guidance to prepare a Greek and Latin module to add to the biology teaching program at secondary level in the following years, which benefited the students.

As a result of this study, in my current professional position as primary science facilitator, every time a lesson is modelled for the primary educators from Grades 4 to 7 in Queensland, five words are selected from each unit and dissected into prefixes, base words and suffixes. Then, the meanings and the definitions are given to the students and encouraged to generate more words from them. The teacher is requested to put up a 'word tree' on the wall in the classroom, which has a trunk with a prefix written on it. The branches are drawn bare and later get filled with leaves with words written on them using the prefix. For example, it the trunk has the word, 'bio' as the prefix, the students bring leaves with words such as biofuel, biodiversity etc., written on them. Once the leaf is glued on to the branch, the students write the definition of the word below the leaf, which is shared with the rest in class. Thus, this deficiency perceived in students during the research gave birth to a new component added to teaching and learning for students' better understanding and retention of science concepts. This has been shared with the other facilitators and primary teachers who attend the Spark workshops so that many teachers could target this issue and reap the benefits.

2b. What role did analogies play in minimising or eliminating the above alternative conceptions?

The average of the pretest raw scores of all the five analogies for correct answers was 64.74%. This improved by 5% after the presentation of the analogy and the posttest average was 69.74%. Similarly, the average for the correct answers and reasons improved from 60.79% to 76.32%. Consequently, the average of the alternative frameworks decreased from 13.63% in the pretest to 9.84% in the posttest. Though this method of calculation cannot be considered statistically viable, it gives an indication of improved understanding and decreased alternative frameworks after the presentation of the analogies. The details of this have been added to appendices in the analysis of individual responses for all the analogies.

Objective 3: To investigate whether the analogies have the potential to extend student thinking to higher levels.

3a. Do analogies simulate thinking in students?

The presentation of analogy on atoms was further studied in great detail due to the time made available for research after the completion of the School's Work Program. The research was extended to investigate the students' thinking process to a certain extent (details in Chapter 3; 3.4.1). This offered valuable data on the thinking process of the students. Of the 23 participants, 21 students were able to pick the right combination of atoms, which are likely to form a compound, discarding the other two choices and they were able to explain the octet rule. These students discerned that bonding will not result in attaining a stable electronic configuration with the discarded atoms and hence, those atoms will not combine with the given atom.

Presuming that a mental process occurred associating the question and students' thinking, they were asked to identify the mental stimulus, or 'what came to their mind', which prompted them to give the particular answer. Seventeen out of 22 remembered the analogy game by associating the game with the related terms or diagrams. Those who remembered the game mentioned the salient features of the game such as the rules, how they played the game and how the students moved to complete an orbit and to attain a stable electronic configuration. It was significant to note that 18 out of 23 students drew a correct generic diagram of a noble gas, using their own imagination. They were given neither the atomic mass nor the number. These revelations are significant because unless the students had exercised critical thinking, they would not have answered the questions correctly. This could also be an indication of the accomplished conceptual change. The students' reflective comments have been added in chapter 3, which bring out the students' thinking associated with the analogy game while answering the questions on the effect of the analogy.

3b. Do analogies help to bring about conceptual change in students?

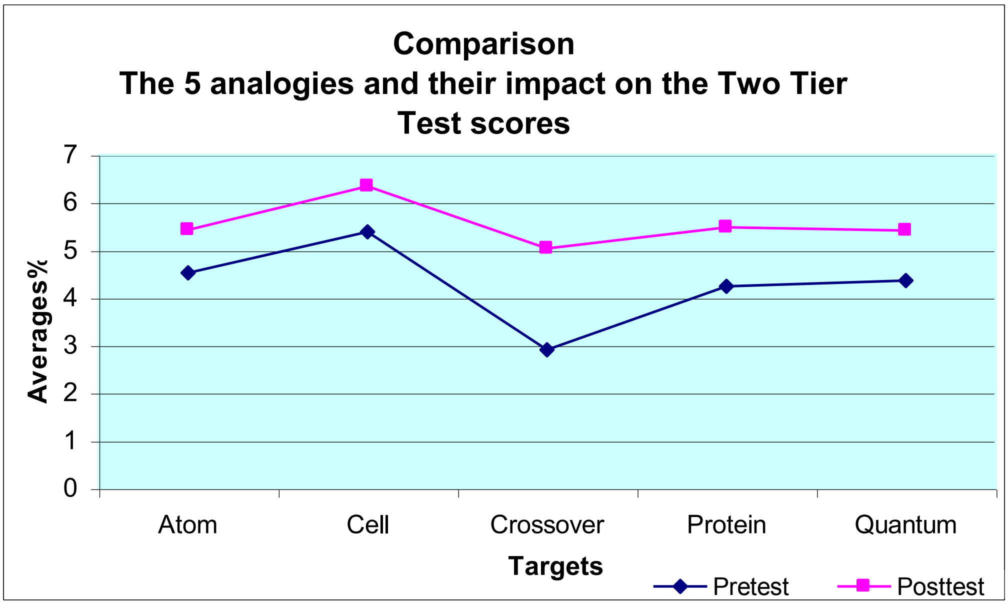


Figure 8.1: Comparison of Pre and Posttest scores of all the 5 analogies.

The improvement in the posttest scores after the presentation of each analogy indicated that the majority of the students benefited from the analogy. The graph in Figure 8.1 points out that irrespective of the kind of analogy presented, there was a positive impact on the understanding of the scientific concept. Could it be substantiated as a result of the conceptual change engendered by the analogies? The paired-sample t-tests conducted to evaluate the effect of the instruction on students' showed that the chromosomal crossing over obtained the Cohen's *d* statistic of 1.05 indicating a large effect size and the others obtained the Cohen's *d* statistic of 0.51, 0.51, 0.52 and 0.42 respectively, indicating a medium effect size. The Cronbach alpha reliability measures for the pretests and posttests for the atom, cell, chromosomal crossing over, protein synthesis and the Quantum Model were 0.47, and 0.56, 0.60 and 0.23, 0.40 and 0.70, 0.67 and 0.60 0.68 and 0.72 respectively. The possible causative factors for low reliability measures as indicated in the above test are discussed later in the chapter. The first hand qualitative data seem to be substantial and dependable and may be deemed as the measure of reliability for the conclusions.

3c. What are the evidences that show that the introduced analogies did or did not enhance students' thinking processes to reach higher order thinking levels?

As stated earlier in chapter 1, the information collected from the quantitative data offered the following details on students' higher order thinking. Twelve out of the fifty randomly included questions (24%) required thinking at higher levels to answer the questions correctly. The raw score averages obtained for these answers in the pretest and posttest were 48% and 55% respectively, which indicates an increase of 8% after the incorporation of the analogies. This led us to consider that the analogies had a positive influence on the understanding of the concepts. Analogies can engender high level thinking in gifted students and is one of the strategies identified by the Williams Model of Affective Interaction (Williams, 1993).

The table on the following page shows the averages of the raw scores obtained for the answers in the pre and posttests, which required higher order thinking:

Table 8.1: Higher order thinking - Raw scores and average

Higher Order Thinking Responses		Number of students	Two-tier Pretest	Two-tier Post test
Q. No	Analogy		Correct answers & reasons	correct answers & reasons
1	Atom	46	14	9
10		46	42	43
1	Cell	38	7	7
2		38	29	31
10		38	24	21
4	Crossing Over	23	7	17
10		23	6	11
1	Electron Configuration	22	10	15
7		22	9	14
10		22	11	11
11		22	0	2
1	Protein Synthesis	25	12	19
	Average %		**46.85**	**54.79**

The table shows an anomaly in pre and posttest scores on the atoms concept as against all the others, which was explained in the individual analysis of answers. The understanding that atoms are very small gave the students the conviction that atoms cannot be broken down further. This is an alternative conception, which is likely to change when they take up nuclear fission and fusion at a higher level of study. This instance has to be treated as an exception, considering that the overall posttest averages showed an increase of 8% after the analogies were incorporated.

Moreover, when students generate analogies, they generalise and apply their previous knowledge, refine and manipulate information to create a new model of what was given to them as an analog. This can be explained as an indication of higher order thinking. The research revealed that this is an innate ability which while not readily achieved by every one in the class; with proper guidance and continued support, a good number of students were able to acquire this skill. Moreover, the sharing of created analogies and discussion with peers in the class had a tremendous impact on the others who listened to them. This gave them the motivation to generate their own analogies. A student in Year 8, who sailed from South Africa to Australia, generated her own analogy of a cell. She imagined the cell to be a ship, nucleus as the captain, DNA as charts, mRNA as the first mate, and cell membrane to the deck, hull and doors. Another student compared her own house to a cell. She said all that fills her house make up the cytoplasm, walls and doors act as cell membrane, lights as the chloroplasts, power box as mitochondrion and hall way as the endoplasmic reticulum. Though these mental images are not perfect, they indicate that the students did reach a higher level in their thinking.

The Year 12 students gave their own analogies, effective replacements for the process of crossing over since the blue and pink paper cut outs could not be twisted. It is obvious that the students exercised critical thinking to give these suggestions to use strings and ribbons instead of paper to improve the analogy. We can consider that these are indications of higher order thinking stimulated by the analogies presented to them, since these were revealed during the post-reflection review.

Year 11 and 12 students have a Section called 'Complex Reasoning' in their written examination, which warrants higher order thinking to answer the questions. The students showed a better understanding of the concepts to answer the questions after the presentation of analogies.

8.2 Implications

8.2.1 The FAR Guide and its Significance in this Research

The purpose of the FAR Guide is to help teachers maximize the benefits and minimize the problems when analogies arise in classroom discourse or in textbooks (Venville 2008). The research findings as posttest results and students' reflective comments indicated that it is reasonable to assume that analogies are effective tools in teaching and learning scientific concepts. When analogies are presented to students in a systematic manner using the FAR Guide, strictly adhering to the specified guidelines, the teaching approach had the potential to maximize the benefits and minimize problems such as developing alternative conceptions. This required a detailed teasing out of the analog and target relationship, which is crucial for understanding the similarity and disparity. When the analog showed a close relationship and less disparity with the target, it enhanced understanding, as indicated by the cut and paste analogy for the chromosomal crossing over by reducing alternate frameworks.

It was understood from the research that most of the alternative conceptions arise as a result of students' inability to comprehend certain concepts, which are above their intellectual level. When analogies lead students to real world situations, the concepts can be broken down to understandable levels, students become motivated to participate and the chance of developing alternative frameworks is lessened. The FAR Guide specifies that the teachers and students need to focus on their procedure and reflect on their method to check for success or failure of an analogy. When the Quantum Mechanical Model was dealt with, it was realised that the analogy had neither the reference to the rules associated with the concept nor the scientists who formulated them. The effect was clearly revealed in the posttest. The post-reflection gave the prompt to remove this defect from the presented analogy, which was done in an amusing manner for the students' better understanding and reinforcement. The revised pictorial analogy was presented after the post-test review. The students appreciated the addition and said that the addition would 'stay on their mind' for a long time and proved it in the ensuing chemistry examination. The research informed that the FAR Guide is flexible to adopt and it is the teacher's and students' need, which directs the use of the Guide. It is possible and certainly advisable, for teachers to adapt their favourite and frequently used analogies to the FAR Guide (Venville, 2008).

8.2.2 Two-Tier Testing and its Significance in this Research

A wide range of specially created two-tier multiple-choice instruments (Treagust 1988, 1995) have been developed and used to determine students' understanding of the concepts in several science disciplines. The administration of two-tier diagnostic instruments by researchers and subsequent analyses of the responses has resulted in the identification of several alternative conceptions that are held by students (Treagust, 2006). An adapted version of the two-tier diagnostic instrument designed by Treagust (1985) was administered to the students before and after the presentation of the analogies. In his keynote address at the Uniserve conference, Treagust (2006) stated the significance of two-tier testing in teaching and learning as:

> The items are designed so that alterative conceptions and scientifically acceptable responses are readily identified. Through the information from these items, teaching can be changed to accommodate identified weaknesses. In responding to these items, students are encouraged to think about the concepts and consider alternative explanations rather than memorise basic facts which are then forgotten.

The choices for the two-tier test were chosen carefully to bring out the flaws in student-understanding and reveal their alternate conceptions. As a result, the research identified many of the alternative conceptions; the test also indicated where the enhancement of understanding had occurred on all the concepts.

8.3 Limitations

Initially, it was decided to present 5 different kinds of analogies, such as a pictorial, game, paper craft and 'animation' to find out which one would prove to be more effective than the other in enhancing student-understanding, higher order thinking and removing alternate conceptions. The data showed that the difference was not statistically significant.

Another reason to include different year levels in the study was due to the eagerness to find out whether the younger or older students would respond to analogies better. Again, the results showed that both responded favourably and the difference was statistically insignificant.

Moreover, the classes allocated for science teaching had to be chosen for easy administration of tests and collection of qualitative data. The curriculum and the school's work program had to be followed without deviating from the expected routine and the analogies had to be fitted in within these limits. The common ground is that none of the students had visited the given concepts earlier.

Further, the conclusion of the research had to be based on the pretest and post test data to a certain extent. Prior to the pretest, a normal routine was followed in explaining the concept as best as possible to suit the year level. The same concept was dealt with again with analogies before the posttest was administered. The repetition of the concept may have offered some benefit to a few students, which is unavoidable.

The students might have been aware that they were under study during the data collection, though no obvious change in their behaviour was perceived. The unexpected occurrence was that a few students changed the correct answers in the pretest to incorrect answers in the posttest. As mentioned earlier, the students became aware of the correct answers only after the posttest. When this anomaly was investigated, it was clear that many took the intervention as a part of their daily routine and were not terribly perturbed about their performance. Whatever the perception may be, the Hawthorne effect could be considered as 'one of the hardest inbuilt biases to eliminate or factor into the design' (Martyn, 2009) which might have been minimal in this study.

The research involved 154 students in this study and would it be more reliable statistically, if a larger group is tested? Would the results be the same? This opens up opportunities for research to many interested educators who would like to use the FAR Guide to present analogies in a systematic manner and find the influence of analogies on student-learning using the two-tier testing.

This particular school where the research was carried out had students from 50 different ethnic groups settled in Australia. English is a second language for many of these students. Though many were able to express themselves to a certain extent, engaging in formal conversations with a teacher with regard to their academic performance didn't happen with ease. It could be due to their ethnic background or lack of confidence in their language skills.

Moreover, finding a suitable place for the interview in a busy high school was not easy and this distracted the interviewee from focusing on the questions. The interview could not be held away from the classroom, because the teacher-researcher had to keep an eye on the remainder of the class. A few interviews conducted at the beginning did not yield worthwhile results. Therefore it was decided to frame questions to probe their thinking and understanding and to elicit their reflections anonymously and/or with names, which the students answered without hesitation and gave valuable data, which was used in the qualitative analysis. The two-tier diagnostic questions were interpreted for a few students when clarification was needed without divulging the answers.

It is a challenge to a teacher-researcher to complete the School's work program and the planned research within the time frame, especially when secondary studies are involved. The pressure was alleviated to a certain extent due to the co-operation of the students, who seemed to enjoy learning with analogies. It was felt that repeating the same test to the same batch for the third time to check their long term memory might give them the advantage of familiarity; also raise questions regarding the use of the teacher's teaching time. But a survey and an informal discussion on the last day of the year revealed that the students had a good memory of the analogy game, which was played about four months earlier.

The high schools in Queensland have no provisions for action research. It is quite different from the research environment in universities. Finding qualitative software and getting trained to use the same was extremely difficult due to constraints. A lot of effort was put in to devise methods to collect valid and reliable qualitative data and in processing the students' responses manually to conclude on students' understanding, perceptions, thinking and opinions on the analogies. This has been presented under specific subheadings for clarification.

Low measures of reliability

The following were considered as supporting factors to indicate the reliability of the test results. When the average of the pretests of the first batches were matched with the averages of the second batches, the average scores did not show any significant difference. The averages were also correlated with the students' annual academic averages to find out whether the correlation was consistent with their achievement in the two-tier diagnostic test results and it was found to be in agreement, indicating reliability to a large extent. The low measures of reliability indicated by the Cronbach alpha reliability measures could be attributed to factors such as small sample size, complexity of the concepts and other hidden factors such as physical and psychological stress. The classes had limited number of students, who could take part in the study. The secondary students, who selected biology and chemistry, were nearly half the number of the students in lower classes. Even if one student answered incorrectly the average percent could drop down considerably due to limited total number in a class.

Moreover, all the chosen science concepts were abstract and complex and the students could have had difficulty in understanding them thoroughly, which could have resulted in inconsistent answers due to guessing. This was revealed when the Year 8 students were asked to explain why some the correct answers were changed to incorrect answers in the posttest. This informs that repeated visits or future construction on these basic concepts may be needed to solve this problem.

Though the analogies helped to clarify the concepts to the majority of the students, there were a few, who could not correlate the features of the analog and the concept to make conclusions about the concept due to individual intellectual differences. In an interview, an OP1 student (Homa) said that though the analogy was clear to her, she didn't need one to understand the concept. She further said that her mind developed pictures when she listened to the teacher and that made her understand and remember the concepts. Another OP1 student (Natalie), a hard working, gifted and talented girl referred to the same mental process.

It is also possible that the limited number of questions included in the diagnostic test could have led to obtaining low measures of reliability. Another underlying cause could be the mood of the students when they took the test after a hot physical education lesson outdoors or during the last lesson at the end of the day. We cannot rule out psychological stress in students due to various personal reasons, which could have affected the results adversely. Since it has been observed and indicated by the qualitative data that analogies did benefit the majority the students, it could be alleged that the research findings are valid.

Being a non-statistician, it was considered sensible to rely on an experienced Statistician for guidance, who also assisted in getting Cronbach's alpha reliability and paired t-tests done. My Supervisor's approval and references such as the one given on the following page by Colosi, 1997) supported the decision at the time.

> One common way of computing correlation values among the questions on your instruments is by using Cronbach's Alpha. In short, Cronbach's alpha splits all the

questions on your instrument every possible way and computes correlation values for them all (we use a computer program for this part). In the end, your computer output generates one number for Cronbach's alpha - and just like a correlation coefficient, the closer it is to one, the higher the reliability estimate of your instrument. Cronbach's alpha is a less conservative estimate of reliability than test/retest. (Colosi. L, 1997)

8.4 Future directions

Due to the improvement in understanding as witnessed in the two-tier posttest results, it was felt that the research was a worthwhile study, which should be shared with other educators, whenever and wherever possible. Since the current position involves working with the primary teachers to enhance science teaching at primary level, the significance of using analogies to teach science concepts has been shared with many primary teachers and primary science facilitators in the North Coast Region already. An extract of the research paper was presented at the International STEM Conference held at Queensland University of Technology, which was attended by educators from 16 countries. It is hoped that these attempts would offer opportunities to teachers to include analogies in their teaching practice and research.

Since the research indicated that analogy is an effective tool to teach and learn, it is easy to guess that an analogical role play might prove effective to improve science instruction at primary level. During the first trial on magnetism, it was noticed that the students expressed great interest and enjoyed the analogical role play. Coll and Treagust (2008) quote Aubusson and Fogwill (2006) 'that the teacher found this process (role play) helpful, the students enjoyed the activity and the teacher felt that the students had learnt something about the concepts under instruction'.

The concept that magnets can help to generate electricity is complex for students in Year 4, and this led to preparing a role play for their better understanding and reinforcement. Impressed by their enthusiasm in participation, other renewable energy sources were added to the role play. All the students participated in the role play, hence the repetition of the scene and principle. A pretest was given to the students after the demonstration lesson to know about their understanding and a posttest after the role play to find out whether the role play enhanced their understanding and minimised their alternative conceptions. The results showed that the average percentage on knowledge and understanding of the sustainable energy sources jumped by 10% after the role play. Moreover, the pretest results showed that 52% of the students had the understanding of the principle of generating electricity using magnets, which increased to 90.5% after the role play. The opinion questions brought out the students' interest in role plays and investigations. Of the 42 students who took part in this survey, 33% preferred the teacher's 'chalk and talk', 90.5% preferred learning through role plays and 73.8% wished to have investigations to learn a scientific concept. The teachers assured that they would include more role plays and experiments in their science lesson in the future. The role play has been extended to other schools. (in Appendix F).

The Preservice teachers, who underwent training at the venue where this research was carried out were involved in the study. The concept of teaching with analogy was shared with them. Though they looked at the study with interest, there was hesitation to venture into this area, even though research has shown that a low performing preservice teacher drastically improved teaching performance using analogy-based pedagogy (James & Scharmann, 2007). It is recommended that the preservice teachers be trained to design analogies to suit the concepts, use the FAR Guide to present them and use diagnostic instruments to identify alternative conceptions and deficiency in understanding before they are released as full-fledged educators.

There is scope for further research on the various aspects of the study. Apart from designing analogical role plays on complex concepts, which is similar to the analogy game used in the research, 'Fill up the Orbit', it would be interesting to find out the difference between using an existing analogy which is verbal and an adapted version of the same designed as a pictorial-verbal analogy/role play and presented to students to study the impact on learning; this research found visual learning is preferred by the students. Students' preferences on verbal, pictorial or pictorial-verbal analogies could also be identified through research. All the analogies presented in this research were generated utilising the available information technology, which made it attractive and engaged the modern generation of learners readily and induced learning. This could be another area to explore. All these attempts might help to improve the quality of science education.

Another current topic of interest in the field of research is exploring the use of multiple analogies for the same concept. Where possible, a range of analogies should be used to target a particular concept….Multiple analogies are effective because each analogy explains only the ideas where it works well, and students can choose the analogies that best suit their experience and thinking needs (Harrison, 2008). With the advancement in medical technology such as fMRI (Functional Magnetic Resonance Imaging), the opportunities are endless. To study the effect of learning with analogies on the brain is a possibility. Finding out whether learning with analogy is brain compatible or non-compatible could be another choice and perhaps, many more.

8.5 Conclusion

The first objective in this research was to investigate the effectiveness of the analogies chosen to present complex concepts, analyse their characteristics, which had the potential to motivate the students, establish relationships between the analog and target and effect meaningful transfer and understanding, thus achieving conceptual change. As inferred from the posttest data and students' comments, the analogies were effective and did enhance the understanding of the concepts Analogies can be motivational in that, as the teacher uses idea from the students' real world experience, a sense of intrinsic interest can potentially be generated. From a teaching perspective, the use of analogies can enhance conceptual change learning since they open new perspectives (Venville & Treagust, 1996)

The second objective was to identify the alternative conceptions associated with the concepts and find out whether the analogies helped to minimise or eliminate these alternative conceptions. '… a teacher needs a starting place for addressing known alternative conceptions and a reliable and valid multiple choice diagnostic test incorporating students' reasoning in selecting responses would appear to provide a relatively straight forward method' (Treagust, 1986). The two-tier diagnostic instrument by Treagust (1985) was adapted to suit the concept and the data was collected for quantitative analysis. The research data indicated the positive influence of the analogies in bringing down the incidence of these defects in student understanding.

The third and final objective was to find out whether analogies stimulate conceptual thinking to effect conceptual change, eventually leading to higher order thinking. Analogies are powerful higher order thinking tools that help scientists and everyday people make sense of the natural phenomena that surround them (Coll & Treagust, 2008). The research provided data as posttest results, student generated analogies and students' reflective comments to indicate that the analogies were successful in achieving what was intended.

This thesis concludes in the words of Gregory Berns, a neuroscientist, who based his book on his fMRI studies and won the 2008 Business Award for his book, 'Iconoclast: A Neuroscientist Reveals How to Think Differently':

> Analogies are brain's shortcuts designed to avoid creative process. … The second point is the most interesting. Lazy by nature, human brain prefers to use analogies instead of starting a hardcore creative thinking session. Analogies are fast and convenient, the brain knows how to deal with them, and hence always tries to use them up before coming up with anything truly original…. Fortunately, the networks that govern both perception and imagination can be reprogrammed. By deploying your attention differently, the frontal cortex, which contains rules for decision making, can reconfigure neural networks so that you can see things that you didn't see before. You need a novel stimulus — either a new piece of information or an unfamiliar environment – to jolt attentional systems awake. The more radical the change, the greater the likelihood of fresh insights (Berns, 2008).

References

ACER: TIMSS (2007). Science pedagogy report: *An international perspective on teaching and learning in mathematics, science and reading.*

Abell, K. A & Lederman, N. G. (2007) Handbook of Research in Science Education. Lawrence Earlbaum Associates Inc.

Aubusson, P.J., Treagust, D.F., & Harrison, A. (2009). *Learning and teaching science with analogies and metaphors.* Sense Publications, Rotterdam.

Berns, G (2008). *Iconoclast: A neuroscientist reveals how to think differently*. Harvard Business Press.

Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning. Abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237-261.

Brown. J. S., Collins. A., & Duguid. P. (1989). *Educational Researcher*; 18 (1) 32-42.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1967). *A study of thinking.* New York: John Wiley & Sons.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Heinemann - Education.

Caine, R. N., Caine, G., McClintic, C., & Klimek, K. J. (2008). *12 Brain/Mind Learning Principles in Action: Developing Executive Functions of the Human Brain.* Sage Publications.

Calik, M., Ayas, A, & Coll, R. K. (2005). A cross-age study on the understanding of chemical solutions and their components. *International Education Journal* (2005, 6(1), 30-41

Calik, M., Ayas, A, & Coll, R. K. (2009) Investigating the effectiveness of an analogy activity in improving students' conceptual change for solution chemistry concepts. *International Journal of Science and Mathematics Education* (2009) 7: 651-676.

Çalık, M., Ayas, A., & Ebenezer, J. (2009) Analogical reasoning for understanding solution rates: students' conceptual change and chemical explanations. *Research in Science & Technological Education* 27(3) 283-308.

Chapman, M. (1988). *Constructive evolution: Origins and development of Piaget's thought.* Cambridge: Cambridge University Press.

Clough. P & Nutbrown, C. (2007). *A student's guide to methodology: Justifying enquiry*. SAGE, Education.

Cohen. L & Manion. L. (2000). *Research Methods in Education*. London: Routledge Falmer

Cohen, L., Manion, L. & Morrison, K. (2007). *Research Methods in Education*. London: Routledge Falmer.

Coll, R. K. & Treagust, D. F. *Inquiry based Teacher- and Student-generate Analogies*. In Harrison, A. G. & Coll, R. K. (2008) Using analogies in middle and secondary science classrooms. Thousand Oaks: Corwin Press.

Costenson & Lawson (1986). In Flick, L. B. (1996). Understanding a Generative Learning Model of Instruction: A Case Study of Elementary Teacher Planning. *Journal of Science Teacher Education*, 7 (2) 95-122.

Curtis, R. V., & Reigeluth, C. M. (1984). The use of analogies in written text. *Instructional Science*, 13, 99-117.

Draganski. B., Gaser. C., Kempermann. H. G., Kuhn. G., Winkler. J., Büchel. C., & May, A.(2006). Development/Plasticity/Repair: Temporal and Spatial Dynamics of Brain Structure Changes during Extensive Learning. *The Journal of Neuroscience*, 26(23): 6314–6317.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development. *Studies in Science Education*, 13, 105-122

Duit, R. (1991a). On the role of analogies and metaphors in learning science. *Science Education*, 75, 649-672.

Duit, R. (1991b). Students' conceptual frameworks: Consequences for learning science. In S. M. Glynn, R. H. Yeany & B. K. Britton (Eds.), *The psychology of learning science* (p 65-85). Hillsdale, NJ: Lawrence Erlbaum.

Erickson, F. (1986). *Qualitative methods in research on teaching*. In Wittrock, M. C. (Ed.), Handbook of research on teaching. 119-161. New York: Macmillan.

Fischer, (1996); Zeichner, (1997). In Abell, S. K. & Lederman, N. G. (1999) Definition of Teacher Research, Handbook of research on science Education. Lawrence Earlbaum Associates Inc.

Flick, L. B. (1996). Understanding a generative learning model of instruction: A case study of elementary teacher planning. *Journal of Science Education*. 7 (2) 95-122.

Fosnot, C. T. (1996). Constructivism: A Psychological Theory of Learning. In *Constructivism: theory, Perspectives and Practice*. Ed. C.T. Fosnot. New York Teachers College Press, 8-43

Gardner, H. (1983). *Frames Of Mind. The theory of Multiple Intelligences*. New York: Basic Books.

Gentner, D. (1983). Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7, 155-170.

Gentner, D. (1989). The mechanisms of analogical learning. In S. Vasniadou & Ortony. A. (Eds.), *Similarity and analogical reasoning*. London: Cambridge University Press.

Gentner, D., Holyoak, K. J., & Kokinov, B. N. (2001). *The analogical mind: perspectives from cognitive science*. MIT Press.

Glynn, S. M., (1989). The teaching with analogies (TWA) model: Explaining concepts in expository text: In K. D. Muth (Ed.), *Children's comprehension of narrative and expository text: Research into practice.* International Reading Association.

Glynn, S. M., (1991). Explaining science concepts. A Teaching-with-Analogies model. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.) The Psychology of learning science. 219-240. Hillsdale, NJ: Earlbaum.

Glynn, S. M. , Duit, R., & Thiele, R. B. (1995). 'Teaching with Analogies: A Strategy for Constructing Knowledge. In Glynn, S. M., & Duit, R. (Eds.). *Learning science in the schools: Research reforming practice.* NJ: Earlbaum.

Goetz, E. T., Alexander, P. A., & Ash, M. J. (1992). Educational psychology: A classroom perspective. New York: Merrill.

Good, R. G., Wandersee, J. H., & Julien, J. S. (1993). Cautionary Notes on the Appeal of the New "Ism"(Constructivism) in Science Education. In K. Tobin (Ed.), *The Practice of constructivism in science education*. NJ: Lawrence Erlbaum Associates.

Goswami, U., (2001). Analogical reasoning in children. In Gentner, D. Holyoak, K. J. & Kokinov. B. N. (Eds.), *The analogical mind: Perspective from cognitive science*. Cambridge, MA: MIT Press.

Grayson, D. J. (2004). Concept substitution: A teaching strategy for helping students disentangle related physics concepts. *American Journal of Physics*, 72 (8), 1126-1133.

Grotzer, T. A., (1996). *Cognitive Issues that Affect Math and Science Learning: Understanding Counts!*: Report on Teaching for Depth in Math and Science, Project Zero, Harvard Graduate.

Guba, E.G. and Lincoln, Y.S. (1989) Fourth generation evaluation. Newbury Park, Ca.: Sage.

Harding, G., & Terrell, S. L. (2006). Strategies *for Alleviating Math Anxiety in the Visual Learner*. Presented at the Math Anxiety Workshop, University of Maryland Maryland.

Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: A case study in grade-10 optics. *Journal of Research in Science Teaching*, 30, 1291-1307.

Harrison, A. G., & Treagust, D. F., (1994). Science analogies. *The Science Teacher,* 61, 40-43.

Harrison, A. G., Treagust, D. F., & Venville.G. J., (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education*, 18, 213-229.

Harrison, A. G., & de Jong. O. (2005). Using multiple analogies: case study of a chemistry teacher's preparations, presentations and reflections. In Boersma, K., Goddhart, M., de Jong. O., & Eijkelhof, H. (Eds.). *Research and quality of science education*. (353-364) Dordrecht: Springer.

Harrison , A. G., & Coll, R. K. (2008). *Using analogies in middle and secondary science classrooms: the FAR Guide- an interesting way to teach with analogies.* Thousand Oaks: Corwin Press.

Haslam. F., & Treagust, D.F. (1987). Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education*, 21 (3) 203-211.

Hesse, M. (1966). *Models and analogies in science*. Notre Dame, IN: Notre Dame Press.

Hiebert, J. & Stigler, J., (1999). The *Teaching Gap: Best Ideas from the World's Teachers for Improving Education in the Classroom.* The Free Press.

Hitchcock, G., & Hughes, D. (1989). *Research and the teacher: A qualitative introduction to school based research.* London: Routledge.

Hofstadter, D. R., (2001). Analogy as the Core of Cognition. In *The Analogical Mind: Perspectives from Cognitive Science.* The MIT Press/Bradford Book. 499-538.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps: Analogy in creative thought.* Cambridge: Bradford.

Holyoak, K.J., Gentner, D., & Kokinov, B. N. (2001) Introduction: The place of analogy in cognition. In Gentner, K. J., Holyoak, K.J. & Kokinov, B. N. (Eds), The analogical mind: Perspectives from cognitive science. P1-19. Cambridge: MIT Press.

James, M. C., & Scharmann, L. C. (2007). Using analogies to improve the performance of pre-service teachers. *Journal of Research in Science Teaching. 44(4),* 565-585.

Karplus, R., & Their, H.D. 1967. *A New Look at Elementary School Science*. Chicago: Rand McNally.

Kemmis, S. and McTaggart, R., eds. (1988) The action research planner, third edition. Victoria: Deakin University.

Kirchhoff, B., & Buckner, R. (2006). Brain Imaging Identifies Best Memorization Strategies. Washington University, *Science Daily.*

Kirchhoff, B. A., & Buckner, R. L. (2006). Functional-Anatomic Correlates of Individual Differences in Memory. *Neuron,* Volume 51 (2) 263-274.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation.* London: Cambridge University Press.

Lawson, A. E. (1988), A better way to teach biology. In Barnum, C.R. (1989). An expanded view of the learning cycle: New ideas about an effective teaching strategy. *Council for Elementary Science International, Monograph and Occasional Paper Series #4.*

Lawson, A. E. (1995). *Science Teaching and the Development of Thinking*, CA, Wadsworth Publishing Company.

Libonate, G., Brunner, G., Burde, D., Williams, M., & Libonate, T. W. (2004). *Ridgewood Analogies: Critical and Creative Thinking across the Curriculum.* Educators Publishing Service, Incorporated. U.S.

McLean, M. S., & Mohr, M. M. (1999). *National Writing Project* (U.S.), Ed.

McHale, T. (2005). *Critical Issue: Using Technology to Improve Student Achievement.* North Central Regional Educational Laboratory (NCREL).

Nunley, K. F. (2002). Active Research Leads to Active Classrooms: *Principal Leadership*, 2 (7), 53-56.

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.

Orgill, M. K., & Thomas, M. (2007). Analogies and the 5E Model. *Science Teacher*, 74, 40-45.

Piaget, J., (1972). In Chapman, M. (1988). *Constructive Evolution: origins and development of Piaget's thought.* London: Cambridge University Press.

Pittman, K. M. (1999). Student-generated analogies: Another way of knowing? *Journal of Research in Science Teaching. 36,* (1) 1-22.

Posner, G. J., Strike, K. A., Hewson. P. W., & Gertzog, W. A. (1982). *Accommodation of a Scientific Conception: Toward a Theory of Conceptual Change.* Department of Education, Cornell University, New York.

Prensky, M. (2001). *Digital Natives, Digital Immigrants on the Horizon*. NCB University Press, 9 (5).

Queensland Syllabus. (2002). *Years 1 to 10 Science.* Queensland School Curriculum Council.

Schecker, H., & Niedderer, H. (1982). *A Contrastive Teaching Strategy: Contrastive teaching in the framework of constructivism.* Institute of Physics Education, University of Bremen.

Schecker, H., & Niedderer, H. (1996). *Contrastive teaching: A strategy to Promote Qualitative Conceptual Understanding of Science.* In Treagust, D. F., Duit, R., & Fraser, B. J. Improving Teaching and Learning in Science and Mathematics, (141-151).Teachers College Press, Columbia University, New York and London.

Shapiro, M. A. (1985). *Analogies, visualization and mental processing of science stories.* Paper presented to the Information Systems Division of the International Communication Association, Honolulu, HI.

Shelley, C. (2003). *Multiple Analogies in Science and Philosophy*. Philadelphia. John Benjamins Publishing Company.

Swartz, R. J. & Parks, S. (1994). *Infusing critical and creative thinking into content instruction: a lesson design handbook for the elementary grades.* CA: Critical Thinking Press & Software.

Thiele, R. B., & Treagust, D. F. (1994). An interpretive examination of high school chemistry teachers' analogical explanations. *Journal of Research in Science Teaching, 31*, 227-242.

Treagust, D.F. (1985). *Diagnostic tests to evaluate students' misconceptions in science.* Presentation at the National Association for Research in Science Teaching, French, Lick Springs, Indiana.

Treagust, D.F. (1986). Evaluating students' misconceptions by means of diagnostic multiple choice items. *Research in Science Education*, 16, (1) Pages 199-207.

Treagust, D. F. (1988) the development and use of diagnostic instruments to evaluate students' misconceptions in science. *International Journal of Science Education,* 10(2), 159-169.

Treagust, D. F. (1989) *Teachers' Use of Analogies to Enhance Students' Conceptual Understanding in Science*, Australian Research Council Project.

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, 413-422.

Treagust, D. F., Venville, G., Harrison, A., Stocklmayer, S., & Thiele, R. (1993). *The FAR Guide for teaching and learning science with analogies.* Presentation at the annual meeting of the Western Australian Science Teacher's Association (CONSTAWA), Muresk.

Treagust, D.F. (1993a). The evolution of an approach for using analogies in teaching and learning science. *Research in Science Education, 23,* 293-301

Treagust, D. F. (1993b). The importance and use of analogies in teaching and learning science more effectively. *Research in Science Education, 23,* 293-301.

Treagust, D.F., Duit, R., & Fraser, B. (1996). *Improving Teaching and Learning in Science and Mathematics.* Teachers College, Columbia University, New York and London.

Treagust, D. F., Harrison, A., & Venville, G (1996). Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education, 18, (2),* 213-229.

Treagust, D. F., Harrison, A., & Venville, G. (1998). Teaching Science Effectively With Analogies: An approach for Preservice and Inservice Teacher Education. *Journal of Science Teacher Education, 9(2),* 85-101.

Treagust, D.F., Duit, R., & Fraser, B. (1996). In Stepans, Dyche & Beiswenger (1998) Improving *Teaching and Learning in Science and Mathematics.* Teachers College, Columbia University, New York and London.

Treagust, D. F., Tan, D., & Chittleborough, G. (July, 2000). *The Use of Diagnostic Instruments for Assessing Students' Chemistry Knowledge.* Paper presented at the Conference of the Australian Science Teachers' Association. CONASTA.

Treagust, D. F. (2001). Using analogies in science teaching to engender students' interests, motivation and understanding. In Clements, M. A. Tairah, H.H., & Ky Wong (Eds.). *Emerging science, mathematics and technical education for all.* (10-26). Gadong, Brunei. Universiti Brunei Darussalam.

Urey, M. & Calik, M. Combining different conceptual change methods within 5E model: A sample teaching design of 'cell' concept and its organelles. *Asia-Pacific Forum on Science Learning and Teaching,* 9(2) p1

Treagust, D. F. (2006). *Enhancing Australian Science Education: Diagnostic assessment in science as a means to improving teaching, learning and retention.* Key address at the Uniserve Science Symposium, University of Sydney.

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. (2002). Teaching about the gene in the genetic information age. *Australian Science Teachers' Journal,* 48(2), 20-24.

Venville, G. J., & Donovan, J. (2006). Analogies for life: a subjective view of analogies and metaphors used to teach about genes and DNA. *Teaching Science, 52 (1)* 18-22.

Venville, G. J. (2008). In In Harrison, A. G., & Coll, R. K. (2008). The Focus-Action-Reflection (FAR Guide-Science Teaching analogies. 22-30.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction, 4,* (Special issue) 45-69.

White, R., & Gunstone, R. (1992). *Probing understanding.* London, Falmer Press.

Williams, F.E. (1993). *The cognitive-affective interaction model for enriching gifted programs.* In J.S. Renzulli (Ed.), Systems and models for developing programs for the gifted and talented (461-484). Highett, Vic.: Hawker Brownlow.

Wittrock, M. C. (1991). *Generative Science Teaching. The content of Science: a constructivist approach to its teaching and learning.* Routledge. - Education, 1994 (p 29)

Young, M.F. (2004). *An ecological psychology of instructional design: Learning and thinking by perceiving-acting systems.* In D. H. Jonassen (Ed.), Handbook of Research for Educational Communications and Technology, Mahwah, NJ: Erlbaum.

Young, M., & McNeese, M. (1995). A situated cognition approach to problem solving. In P. Hancock, J. Flach, J. Caid & K. Vicente (Eds.) *Local Applications of the Ecological Approach to Human Machine Systems*, (p 359-391). Hillsdale, NJ: Erlbaum.

Young et al. (1997). The unit of analysis for situated assessment. *Instructional Science, 25(2)*, 133-150.

Zohr, J. & Dori, Y. J., (2003) Higher Order Thinking Skills and Low-Achieving Students: Are they mutually exclusive? *The Journal of the Learning Sciences. 12 (2)*, 145-181.

Zoller, U. & Tsaparlis, G. (1997) Higher and lower-order cognitive skills. *Research in Science Education,* 27(1) 117-130.

World Wide Web references

AGPA. (2001). Using Analogies. Retrieved August 15, 2004, from www.agpa.uakron.edu/p16/btp.php?id=using-analogies

Aubusson, P. (2002). Using metaphor to make sense and build theory in qualitative analysis. The Qualitative Report, 7(4). Retrieved September 22, 2003, from http://www.nova.edu/ssss/QR/QR7-4/aubusson.html

Ausubel, 1960; Gagne, Briggs & Wager, 1988; Rumelhart & Norman, 1981. In Shu-Ling, L. (1998). The effect of visual display of analogies using computer based learning. International Journal of Instructional Media. 25. Retrieved September, 5, 2004, from https://www.questia.com/

Barnum, C. R. (1989). An expanded view of the learning cycle. New ideas about an effective teaching strategy. Council for Elementary Science International. Monograph and Occasional Paper Series 4. Retrieved May 28, 2009, from http://www.scribd.com/doc/6703852/A-at-In

Beyer. (1987) In Knapp, C. E. (2000). Thinking in Outdoor Inquiry. ERIC Clearinghouse on Rural Education and Small Schools. Charleston. WV. ERIC Identifier: ED 348198. Retrieved July 12, 2004, from http://www.ericdigests.org/1992-2/outdoor.htm

Black & Solomon, 1978, Duit, 1991, & Jonassen, 1994. In Shu-Ling, L. (1998). The effect of visual display of analogies using computer based learning. International Journal of Instructional Media. 25. Retrieved September 5, 2004, from https://www.questia.com/

Cadena, F. (2002) Implementing Innovative Visual Aids in Engineering Education. Retrieved June 26, 2008, from http://spacegrant.nmsu.edu/NMSU/2002/cadena.pdf

Colosi, L. (1997) Quantitative research: Reliability and Validity. Retrieved September 22, 2011 from http://www.pdx.edu/sites/www.pdx.edu.studentaffairs/files/media_assets/QuanRshRel&Val.pdf

Cromie, W. J. (February, 1996). Research Links Sleep, Dreams and Learning. Article published in Harvard Gazette. Retrieved September 5, 2004, from www.news.harvard.edu/gazette/1996/

Dick, B. (2000) A beginner's guide to action research [On line]. Retrieved September 20, 2011, from http://www.scu.edu.au/schools/gcm/ar/arp/guide.html

Dickinson, D. (1998) Creating The Future: Perspectives on Educational Change. (online) New Horizons for Learning. Retrieved June 3, 2009, from www.newhorizons.org/future/Creating_the_Future/crfut_dickinson.html

Downing, C. (1999) Analyzing analogies. Access Excellence. Retrieved September 5, 2004 from http://www.accessexcellence.org/LC/SER/JA/analogy/cdeana19.html

Faust, J., Ginno, E. A., Laherty, J. & Manuel, K. (2001). Teaching information literacy to Generation Y: Tested Strategies for reaching the headphone-wearing, itchy mouse- fingered, and frequently paged. Poster for the ACRL 10th National Conference. Retrieved September 10, 2005, from http://www.library.csuhayward.edu/staff/ginno/ACRL/demograp.htm

Gaser, G. & Schlaug, G. (2006) Brain structures differ between musicians and non-musicians. Annals of the New York Academy of Sciences. 999 (p 514-517). Retrieved on September 12, 2008, from http://www3.interscience.wiley.com/journal/118876641/abstract?CRETRY=1&SRETRY=0

Glynn. S., Russell. A., & Noah. D.(1997). Teaching Science Concepts to Children: The Role of Analogies. Retrieved September 22, 2003, from http://www.coe.uga.edu/edpsych/faculty/glynn/twa.html

Gokdere, M. & Calik, M. (2010). A cross age study of Turkish students' mental models: An atom Concept. Didactica Slovenica Pedagosca Obzorja 25(2) 185-199. Retrieved August, 20, 2011 from http://ktu.academia.edu/MUAMMERCALIK/Papers/244152

Gordon. L & Obbink. J (1993) Teaching biotechnology by analogies and models. Retrieved September 22, 2003, from http://www.accessexcellence.org/AE/AEPC/WWC/1993/teaching.html

Harding, G. & Terrell, S. L. (September, 2006) Presented at the Maths Anxiety Workshop, University of Maryland University College. Retrieved January 7, 2008, from http://polaris.umuc.edu/ctl-content/webtycho/math/plan4.pdf

Hitchhock, D. (1996) In his review of Mental leaps: Analogy in creative thought by Holyoak, K. J., & Thagard, P. (1995) Informal logic Vol 18, No. 12. Retrieved September 18, 2009 from http://www.phaenex.uwindsor.ca/ojs/leddy/index.php/informal_logic/article/view/2388/1830

Inspiration Software Inc., (July, 2003). Graphic Organizers: A Review of Scientifically Based Research. The Institute for the Development of Research in Education (IARE) at AEL. Retrieved January 7, 2008, from http://region2library.org/DATA/Inspiration%20presentation/Print%20Resources/SBR_summary.pdf

Key, J. P., (1997). Research Design in Occupational Education. Questionnaire and interview as data gathering tools. Data Tools, Oklahoma State University. Retrieved June 5, 2005, from http://www.okstate.edu/ag/agedcm4h/academic/aged5980a/5980/newpage16.htm

Kirkwood, M. (2002). Infusing Thinking in the Curriculum Retrieved September 8, 2002, from http://www.scre.ac.uk/rie/nl69/nl69kirkwood.html

Knapp, C. E. (2000) Thinking in Outdoor Inquiry. ERIC Clearing house on Rural Education and Small Schools. ERIC Identifier: ED 348198. Retrieved July 12, 2004, from http://www.ericdigests.org/1992-2/outdoor.htm

Lee. H, et al. (2007). Anatomical Traces of Vocabulary Acquisition in the Adolescent Brain. Retrieved August 5, 2009, DOI 10.1523/JNEUROSCI.4442-06.2007.

Maguire, E. A., Woollett, K., & Spiers, H. J. (2006) London Taxi Drivers and Bus Drivers: A Structural MRI and Neuropsychological Analysis. Retrieved on August 5, 2009,. DOI 10.1002/hipo.20233

Mayoux, L (2003) Thinking it through diagrams in impact assessment, Program on Participatory Research and Gender analysis, WISE Development Ltd. Retrieved May 12, 2010, from www2.ids.ac.uk/impact/files/tools/mayoux_diagrams_overview.doc

McNeil, S. (2009). Visualizing Mental Models: Understanding Cognitive Change to Support Teaching and Learning of Multimedia Design and Development Retrieved December 10, 2010, from http://it.coe.uga.edu/itforum/paper111/McNeil.pdf

Moskulyuk, A. (2008). A review on Iconoclast: A Neuroscientist Reveals How to Think Differently. Retrieved February, 5, 2011, from http://www.moskalyuk.com/blog/why-thinking-in-analogies-is-dangerous/1587

Neill, J. (2006). Analysis of Professional Literature: Qualitative Research. Retrieved July 6, 2007, from http://wilderdom.com/OEcourses/PROFLIT/Class6Qualitative1.htm

Novak, J.D. & Canas, A.J. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them, Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida. Institute for Human and Machine Cognition. Retrieved December 2, 2008, from http://cmap.ihmc.us/Publications/

Nunley, K. F. (2004). Layered Curriculum (n.d.) Retrieved December 28, 2005, from http://www.roxbury.net/psch02listen.html

Orban, P., Rauchs, G., Balteau, E., Degueldre, C., Luxen, A., Maquet, P. & Peigneux, P. (2006). Sleep after spatial learning promotes covert reorganisation of brain activity. Proceedings of The National Academy of Sciences of the United States of America. Retrieved July 7, 2008, from http://www.pnas.org/content/103/18/7124.short

Price.et al. (2007). Anatomical traces of vocabulary acquisition in the Adolescent Brain. Retrieved November 2, 2009, from The Journal of Neuroscience, 27(5):1184-1189; doi:10.1523/JNEUROSCI.4442-06.2007 http://www.jneurosci.org/cgi/content/abstract/27/5/1184

Schwartz, S., Maquet, P., & Frith, C. (2002). Neural correlates of perpetual learning: a functional MRI study of visual texture discrimination. The National Academy of Sciences of the United States of America. Retrieved July 7, 2004, from http://www.pnas.org/content/99/26/17137.short

Shuttleworth, M. (2009) Hawthorne Effect. Retrieved September 22, from http://www.experiment-resources.com/hawthorne-effect.html

Shu-Ling, L. (1998). Learning. International Journal of Instructional Media, Vol. 25. Retrieved from April 8, 2002, from https://www.questia.com/

Smith, J. A. (1994) Translation of Aristotle's On the Soul. Retrieved Feb 12, 2004 from http://classics.mit.edu/Aristotle/soul.3.iii.html

Smith, A. T., Singh, K. D. & Greenlee, M. W. (2000). Attentional suppression of activity in the human visual cortex. NeuroReport. 11 (2) p 271-278. Retrieved July 28, 2004 from http://journals.lww.com/neuroreport/Abstract/2000/02070/Attentional_suppression_of_activity_in_the_human.10.aspx

Treagust, D. F. (September, 2006) Diagnostic assessment in science as a means to improving teaching, learning and retention. Paper presented at the Proceedings of the Assessment in Science Teaching and Learning Symposium. Retrieved April 11, 2009, from http://sydney.edu.au/science/uniserve_science/pubs/procs/2006/treagust.pdf

UNESCO (1999). Science for the Twenty First Century. Retrieved September, 7, 2002, from http://unesdoc.unesco.org/images/0012/001207/120706e.pdf

Woollett, K., Maguire, E. A., & Spiers, H. J. (2006). Talent in the taxi: a model system for exploring expertise. The Royal Society. Retrieved November 12, 2009, from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2677577/

Zollman, D & Robello, N. S. (1998). Learning Cycles – Curricula Based on Research, Physics Education Research Conference. University of Nebraska. Retrieved September 9, 2002, from http://web.phys.ksu.edu/papers/concepts/LCIntro.pdf

Zoller. U. & Pushkin. D. (2007). Matching Higher-Order Cognitive Skills (HOCS) promotion goals with problem-based laboratory practice in a freshman organic chemistry course. Retrieved August 20, 2011, from http://www.rsc.org/images/Zoller%20paper%20final_tcm18-85039.pdf

~~References~~

~~ACER: TIMSS (2007). Science pedagogy report: *An international perspective on teaching and learning in mathematics, science and reading*.~~

~~Aubusson, P.J., Treagust, D.F. & Harrison, A. (2009), *Learning and teaching science with analogies and metaphors*. Sense Publications, Rotterdam.~~

~~Berns, G (2008) ICONOCLAST: *A NEUROSCIENTIST REVEALS HOW TO THINK DIFFERENTLY*. Harvard Business Press, 14 August 2008~~

~~Brown. J. S., Collins. A., & Duguid. P., (1989) *Educational Researcher*, 18 (1) (p. 32-42).~~

~~Bruner, J. S., Goodnow, J. J. & Austin, G. A. (1967). *A study of thinking*. New York: John Wiley & Sons. Inc. (1956). Reprint Transaction Publishers, NJ.~~

~~Bybee, R. W. (1997) Achieving scientific literacy: *from purposes to practices.* Heinemann - Education.~~

~~Caine, R. N., Caine, G., McClintic, C. & Klimek, K. J. (2009) 12 Brain/Mind Learning Principles in Action: *Developing Executive Functions of the Human Brain.* Sage Publications.~~

~~Chapman, M. (1988). Constructive Evolution: *Origins and development of Piaget's thought*. London: Cambridge University Press.~~

~~Clough. P & Nutbrown, C. (2007). A student's guide to methodology: Justifying enquiry. (p 183) SAGE, Education.~~

~~Costenson and Lawson (1986) In Flick, L. B. Understanding a Generative Learning Model of Instruction: *A Case Study of Elementary Teacher Planning*. Journal of Science Teacher Education, 7 (2) 95-122. Kluwer Academic publishers.~~

~~Cohen, L., Manion, L. & Morrison, K. (2007) Research Methods in Education 5th edn (London: Routledge Falmer).~~

~~Curtis, R. V., & Reigeluth, C. M. (1984) The use of analogies in written text. *Instructional Science*, 13 (p 99-117)~~

~~Daniel C. Edelson, D. C. (2001) Learning-for-use: *A framework for the design of technology-supported inquiry activities*. Journal of Research in Science Teaching, 38 (3). John Wiley & Sons, Inc.~~

~~Duit, R. (1991). On the role of analogies and metaphors in learning science, *Science Education*, *75*, (p 649-672).~~

~~Duit, R. (1991a). On the role of analogies and metaphors in learning science, *Science Education*, *75*, (p 649-672).~~

~~Duit, R. (1991b). Students' conceptual frameworks: *Consequences for learning science*. In S. M. Glynn, R. H. Yeany & B. K. Britton (Eds.), *The psychology of learning science* (p 65-85). Hillsdale, NJ: Lawrence Erlbaum.~~

~~Draganski. B., Gaser. C., Kempermann. H. G., Kuhn. G., Winkler. J., Büchel. C., and May. A.(2006). Development/Plasticity/Repair: *Temporal and Spatial Dynamics of Brain Structure Changes during Extensive Learning*. The Journal of Neuroscience, June 7, 2006 • 26(23):6314–6317.~~

~~Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed.) (p119-161). New York: Macmillan.~~

~~Flick, L. B. (1996) Understanding a generative learning model of instruction: *A case study of elementary teacher planning. Journal of Science Education*. 7 (2) (p 95-122). Springer Netherlands.~~

~~Fosnot, C. T. (1996) Constructivism: *A Psychological Theory of Learning*. In *Constructivism: theory, Perspectives and Practice.* Ed. C.T. Fosnot. New York Teachers College Press,. 8-43~~

~~Gardner, H. (1993) Frames Of Mind. *The theory of Multiple Intelligences.* New York: Basic Books.~~

~~Gentner, D. (1983). Structure mapping: *A theoretical framework for analogy*. Cognitive Science, 7, (p155-170).~~

~~Gentner, D. (1989). The mechanisms of analogical learning. In S. Vasniadou & A. Ortony (Eds.), *Similarity and analogical Reasoning* (p199-241). London: Cambridge University Press.~~

~~Gentner, D., Holyoak, K. J. & Kokinov, B. N. (2001) The analogical mind: *perspectives from cognitive science.* MIT Press.~~

~~Glynn, S. M. (1989). The teaching with analogies (TWA) model: *Explaining concepts in expository text:* In K. D. Muth (Ed.), *Children's comprehension of narrative and expository text: Research into practice* (p 99-129). Newark: International Reading Association.~~

~~Glynn, S. M. , Duit, R., & Thiele. R. B. (1995). 'Teaching with Analogies: *A Strategy for Constructing Knowledge*. In S. M. Glynn and R. Duit. (Eds.). *Learning science in the schools: Research reforming practice* (pp247-273). Mahwah,. NJ: Earlbaum.~~

~~Good, R. G., Wandersee, J. H..& Julien, J. S. (1993). Cautionary Notes on the Appeal of the New" Ism"(Constructivism) in Science Education. In K. Tobin (Ed.), *The Practice of constructivism in science education* (p 71-87) Hillsdale, NJ: Lawrence Erlbaum Associates.~~

~~Goswami, U. (2001). Analogical reasoning in children. In D. Gentner, K. J. Holyoak, & B. N. Kokinov. (Eds.), *The analogical mind: Perspective from cognitive science* (p 437-470). Cambridge, MA: MIT Press.~~

~~Grayson, D. J. (2004) Concept substitution: *A teaching strategy for helping students disentangle related physics concepts.* American Journal of Physics, 72 (8), (p. 1126-1133)~~

~~Grotzer, T. A. (1996) Cognitive Issues that Affect Math and Science Learning: *Understanding Counts!: Teaching for Depth in Math and Science,* Math/Science Matters: Resource Booklets on Research in Math and Science Learning, Booklet 1, Project Zero, Harvard Graduate School of Education.~~

~~Harding, G. & Terrell, S. L. (2006) *Strategies for Alleviating Math Anxiety in the Visual Learner* . Presented at the Math Anxiety Workshop, University of Maryland University College (UMUC) September 11 – 22, 2006~~

~~Harrison, A. G., & Treagust, D. F. (1993). Teaching with analogies: *A case study in grade 10 optics. Journal of Research in Science Teaching, 30*, (p1291-1307).~~

~~Harrison, A. G., & Treagust, D. F. (1994). Science analogies. *The Science Teacher, 61*, (p 40-43).~~

~~Harrison, A. G., & Treagust, D. F & Venville.G. J. (1996). *Using an analogical teaching approach to engender conceptual change*. International Journal of Science Education, 18, (p 213-229).~~

~~Haslam. F., & Treagust, D.F. (1987) *Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. Journal of Biological Education*, 21 (3) (p 203-211).~~

~~Hesse, M. (1966). *Models and analogies in science.* Notre Dame, IN: Notre Dame Press.~~

~~Hiebert, J. & Stigler, J. (1999). The Teaching Gap: *Best Ideas from the World's Teachers for Improving Education in the Classroom*. The Free Press.~~

~~Hofstadter, D. R. (2001) 'Analogy as the Core of Cognition'. In *The Analogical Mind: Perspectives from Cognitive Science*. The MIT Press/Bradford Book. pp. 499-538.~~

~~Holyoak, K. J., & Thagard, P. (1995). *Mental leaps: Analogy in creative thought.* Cambridge: Bradford.~~

~~Hitchcock, G., & Hughes, D. (1989). *Research and the teacher: A qualitative introduction to school based research*. London: Routledge.~~

~~Kirchhoff . B., & Buckner. R., *Brain Imaging Identifies Best Memorization Strategies.*~~

~~Washington University in St. Louis (2006, August 10). ScienceDaily.~~

~~Kirchhoff, B. A. & Buckner, R. L. July 19, 2006. *Functional Anatomic Correlates of Individual Differences in Memory*. Neuron, Volume 51, Issue 2, 20. July 2006, Pages 263-274~~

~~Lave, J.,& Wenger. E., (1991), Situated Learning: *Legitimate Peripheral Participation.* London: Cambridge University Press.~~

~~Lawson, A. E. (1995) *Science Teaching and the Development of Thinking*, CA, Wadsworth Publishing Company.~~

~~Lee. H, et al. (2007) *Anatomical Traces of Vocabulary Acquisition in the Adolescent Brain*. DOI 10.1523/JNEUROSCI.4442-06.2007~~

~~Maguire, E. A., Woollett, K. & Spiers, H.J.(2006) London Taxi Drivers and Bus Drivers: A Structural MRI and Neuropsychological Analysis. DOI 10.1002/hipo.20233~~

~~McHale, T. (2005). Critical Issue: *Using Technology to Improve Student Achievement*. North Central Regional Educational Laboratory (NCREL), Paper originally published in 1999 and updated in 2005.~~

~~MacLean, M. S. & Mohr, M. M. (1999). National Writing Project (U.S.), Ed.~~

~~Nunley, K. F. (2002). *Active Research Leads to Active Classrooms: Principal Leadership,* 2 (7), p 53-56.~~

~~Orgill, M. K. & Thomas, M. (2007). *Analogies and the 5E Model*. *Science Teacher*, 74, (p 40-45).~~

~~Posner, G. J., Strike, K. A., Hewson. P. W. & Gertzog, W. A. (1982). Accommodation of a Scientific Conception: *Toward a Theory of Conceptual Change*. Department of Education, Cornell University, New York.~~

~~Prensky, M. (2001). Digital Natives, Digital Immigrants. *On the Horizon.* NCB University Press, 9 (5).~~

~~Ridgewood Analogies (2004). Educators Publishing Service, Incorporated. U.S.~~

~~Schecker, H. & Niedderer, H. (1982) A Contrastive Teaching Strategy: *Contrastive teaching in the framework of constructivism*. Institute of Physics Education, University of Bremen.~~

~~Shelley, C. (2003). *Multiple Analogies in Science and Philosophy*. Philadelphia. John Benjamins Publishing Company.~~

~~Sridevi, K. V. & Gohit, R.K. *Constructivism in Science Education*. Michigan: Discovery House Publishers.~~

~~Swartz, R. J. & Parks, S. (1994) Infusing critical and creative thinking into content instruction: *a lesson design handbook for the elementary grades*. CA: Critical Thinking Press & Software.~~

~~Thiele, R. B., & Treagust, D. F. (1994). *An interpretive examination of high school chemistry teachers' analogical explanations*. Journal of Research in Science Teaching, 31, (p 227-242).~~

~~Pittman, K. M. (1999) Student-generated analogies: *Another way of knowing*? Journal of Research in Science Teaching. 36, (p1-22).~~

~~Treagust, D.F. (1985). *Diagnostic tests to evaluate students' misconceptions in science.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, French, Lick Springs, Indiana.~~

~~Treagust, D.F. & Haslam, F. (1987). *Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument.* Journal of Biological Education, 21(3), 203-211.~~

~~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, (p 413-422).~~

~~Treagust, D.F. (1993a) *THE EVOLUTION OF AN APPROACH FOR USING ANALOGIES IN TEACHING AND LEARNING SCIENCE* Research in Science Education, 1993, 23, 293-301~~

~~Treagust, D. F. (1993b). *The importance and use of analogies in teaching and learning science more effectively.* Research in Science Education, 23, (p 293-301).~~

~~Treagust, D., Venville, G., Harrison, A., Stocklmayer, S., & Thiele, R. (1993c). *The FAR Guide for teaching and learning science with analogies*. Paper presented at the annual meeting of the Western Australian Science Teacher's Association (CONSTAWA), Muresk.~~

~~Treagust, D. F. (2006). Enhancing Australian Science Education: *Diagnostic assessment in science as a means to improving teaching, learning and retention* at the Uniserve Science Symposium, University of Sydney, on 28 September 2006.~~

~~Treagust, D. F. & Coll, R. K. (2008) Inquiry-based teacher and student-generated analogies in In Haarrison & Coll, R. K *Using ANALOGIES in middle and secondary SCIENCE Classrooms* (P66)~~

~~Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, (p 45-69).~~

~~White, R., & Gunstone, R. (1992). *Probing understanding*. London, Falmer Press.~~

~~Young, M.F. (2004). An ecological psychology of instructional design: *Learning and thinking by perceiving-acting systems*. In D. H. Jonassen (Ed.), Handbook of Research for Educational Communications and Technology, 2nd ed. Mahwah, NJ: Erlbaum.~~

~~Young, M. & McNeese, M. (1995). A situated cognition approach to problem solving. In P. Hancock, J. Flach, J. Caid & K. Vicente (Eds.) *Local Applications of the Ecological Approach to Human Machine Systems*, (pp. 359-391). Hillsdale, NJ: Erlbaum.~~

~~Young et al (1997). *The unit of analysis for situated assessment.* Instructional Science, 25(2), 133-150.~~

~~World Wide Web references~~

~~The AGPA (2001). Using Analogies. Retrieved 15 August 2004, from www.agpa.uakron.edu/p16/btp.php?id=using-analogies~~

~~Aubusson, P. (2002, December). Using metaphor to make sense and build theory in qualitative analysis. The Qualitative Report, 7(4). Retrieved 22 September 2003, from http://www.nova.edu/ssss/QR/QR7-4/aubusson.html~~

~~Dickinson, D. (1998) Creating The Future: Perspectives on Educational Change. (online) New Horizons for Learning. Retrieved 3 June 2009 from www.newhorizons.org/future/Creating_the_Future/crfut_dickinson.html~~

~~Gardner, H INTELLIGENCE IN SEVEN STEPS in Learning Through Many Kinds of Intelligence Dickson, D (2000). Retrieved 27 May 2009 from www.newhorizons.org/strtegies/mi/dickinson_mi.html~~

~~Gaser, G. & Schlaug, G. (2006) Brain structures differ between musicians and non-musicians. Annals of the New York Academy of Sciences. 999 Published online 24 Jan 2006. (p 514-517). Retrieved on 12 September 2008 from http://www3.interscience.wiley.com/journal/118876641/abstract?CRETRY=1&SRETRY=0~~

~~Gordon. L & Obbink. J (1993) TEACHING BIOTECHNOLOGY BY ANALOGIES AND MODELS Retrieved 22 September 2003, from http://www.accessexcellence.org/AE/AEPC/WWC/1993/teaching.html~~

~~Glynn. S., Russell. A. & Noah. D.(1997). Teaching Science Concepts to Children: The Role of Analogies. Retrieved 22 September 2003 from http://www.coe.uga.edu/edpsych/faculty/glynn/twa.html~~

~~Harding, G. & Terrell, S. L. (2006) Presented at the Maths Anxiety Workshop, University of Maryland University College. (September 11-22, 2006. Retrieved January 2008 from http://polaris.umuc.edu/ctl-content/webtycho/math/plan4.pdf~~

~~Fischer, (1996); Zeichner, (1997). In Definition of Teacher Research, Handbook of research on science Education by Abell, S. K. & Lederman, N. G. Retrieved 22 July 2005 from~~
~~http://books.google.com.au/books?id=Rd31m3-RU3oC&pg=PA1208&lpg=PA1208&dq=Fischer+%26+Zeichner&source=bl&ots=3X3edaSnwf&sig=oI2YDxAEbu1Rk9XPddRs-P-A8A&hl=en&ei=WQBVTJvgCoqqce6v5cAM&sa=X&oi=book_result&ct=result&resnum=3&ved=0CCAQ6AEwAg#v=onepage&q=Fischer%20%26%20Zeichner&f=false~~

~~Kirkwood, M. (2002). *Infusing Thinking in the Curriculum* Retrieved September 8, 2002, from http://www.scre.ac.uk/rie/nl69/nl69kirkwood.html~~

~~Mayoux, L (2003) THINKING IT THROUGH DIAGRAMS in impact assessment, Program on Participatory Research and Gender analysis, WISE Development Ltd. Retrieved 12 May 2010 from~~
~~www2.ids.ac.uk/impact/files/tools/mayoux_diagrams_overview.doc~~
~~Novak, J.D. &Canas, A.J. (2008) The Theory Underlying Concept Maps and How to Construct and Use Them, Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida. Institute for Human and Machine Cognition, 2008, available at: http://cmap.ihmc.us/Publications/~~

~~Price.et al., Anatomical traces of vocabulary acquisition in the Adolescent Brain. Retrieved November 2009 from The Journal of Neuroscience, January 31, 2007, 27(5):1184-1189; doi:10.1523/JNEUROSCI.4442-06.2007~~
~~http://www.jneurosci.org/cgi/content/abstract/27/5/1184~~

~~Schwartz, S., Maquet, P., & Frith, C. (2002). Neural correlates of perpetual learning: a functional MRI study of visual texture discrimination. Proceedings of The National Academy of Sciences of the United States of America. Retrieved July 2004 from~~
~~http://www.pnas.org/content/99/26/17137.short~~

~~McNeil, S. Visualizing Mental Models: Understanding Cognitive Change to Support Teaching and Learning of Multimedia Design and Development Retrieved December 2010 from http://it.coe.uga.edu/itforum/paper111/McNeil.pdf~~

~~Nunley, K. F. (2004) *Layered Curriculum* (n.d.) Retrieved December 28, 2005, from http://www.roxbury.net/psch02listen.html~~

~~Orban, P., Rauchs, G., Balteau, E., Degueldre, C., Luxen, A., Maquet, P. & Peigneux, P. (2005). Sleep after spatial learning promotes covert reorganisation of brain activity. Proceedings of The National Academy of Sciences of the United States of America. Retrieved July 2008 from http://www.pnas.org/content/103/18/7124.short~~

~~Shu-Ling, L. (2002). Learning. International Journal of Instructional Media, Vol. 25. Retrieved from April 8, 2002, from https://www.questia.com/~~

~~Smith, S. S. C. & Shelley, J. O. (2002) A vision of education in 2010. ERIC, Educational Technology 42 (4) p21-23.~~

~~Smith, A. T., Singh, K. D. & Greenlee, M. W. (2000). Attentional suppression of activity in the human visual cortex. NeuroReport. 11 (2) p 271-278. Retrieved 28 July 2004 from http://journals.lww.com/neuroreport/Abstract/2000/02070/Attentional_suppression_of_activity_in_the_human.10.aspx~~

~~Sutton, J. (1996). Research Links Sleep, Dreams and Learning. Quoted by Cromie, W. J. Harvard Gazette Archives. Retrieved September 2004 from www.news.harvard.edu/gazette/1996/~~

~~UNESCO (1999). Science for the Twenty First Century. Retrieved September 2002 from http://unesdoc.unesco.org/images/0012/001207/120706e.pdf~~

~~Woollett, K., Maguire, E. A., & Spiers, H. J. (2006). Talent in the taxi: a model system for exploring expertise. Philos Trans R Soc Lond B Biol Sci. 2009 May 27 364(1522) (p1407-1416). The Royal Society. Retrieved November 2009 from~~

APPENDIX A

(Relates to Chapter 3)

ATOMS AND MOLECULES

Appendix A 1. a

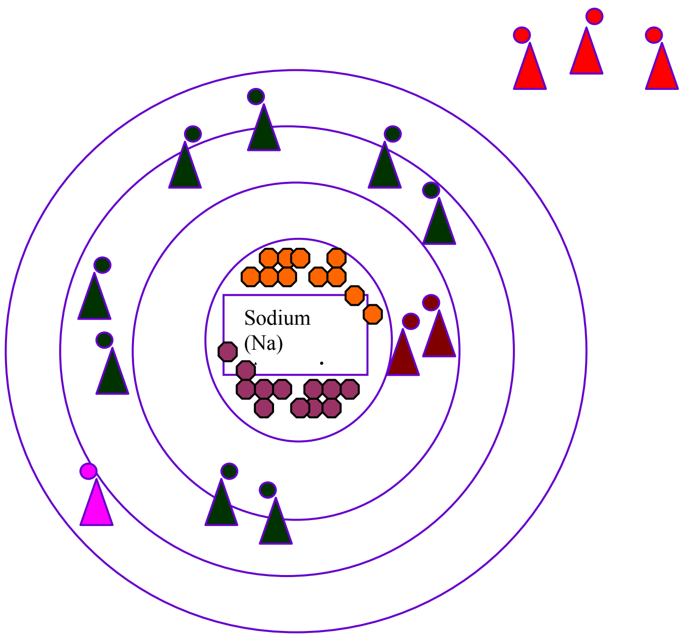
Chapter 3

Analogy 1 - Fill up the Orbit

1. Intervention: a. Using the FAR Guide:

Focus

The students were given a colourful diagram of the handout (See Appendix A.1) and the rules of the game. A thorough discussion followed. They were given sufficient time to clarify their doubts before they proceeded to the venue to play the game. Fluorine and Sodium were the atoms chosen for the trial games and the cards showed the name, symbol, atomic numbers and masses of the chosen atoms as shown in Appendix A.2. The information shown in Figure A.3 were put up on the board as and when the students raised these points either during analog–target mapping or during the class discussion, which followed. The students copied these tables for their future reference.



Legend:

Inner Circle: Nucleus, Circles: Orbits, Students: Electrons, Protons: , Neutrons:

Figure A. 1 Student-handout

Structure of an Atom – a game to play

Appendix A 1. b & c

b. Cards used in the trial

GAME 1	GAME 2
F 9	Na 11
19	23
FLUORINE	SODIUM

Figure A. 2 Cards used in the trial

c. Analog - Target mapping

	Analog (game)	Target (aimed at learning)
1	Students moving	Electrons spinning
2	Central circle	Nucleus of the atom
3	Piece of paper containing the number of Sub-atomic particles	Protons (+ charge), Neutrons (no charge)
4	Inner circle accommodating 2 students	1st orbit containing maximum 2 electrons (Duplet rule)
5	Second circle accommodating 8 students	2nd orbit containing maximum 8 electrons (Octet rule)
6	Outermost circle can have up to 18 students	Outer orbit contains the remainder of the electrons

Table A. 1 Analog - Target mapping

	Features, not like the real atom
1	Size
2	People instead of particles
3	Game –clear lines showing orbits
4	No spinning
5	Written atomic mass instead of particles

Focus

APPENDIX A. 2

The FAR Guide for teaching and learning about Atoms and Molecules

Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Atoms and Molecules' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with similar games like the chosen analog, 'Fill up the orbit'.

Action

Likes	Discuss the features of analog and the scientific concept. Draw similarities between them.	An atom could be compared to the chosen game, in which the central circle represents the nucleus of the atom and it contains the card showing the number of protons and neutrons. The students standing around in concentric circles represent the electrons. (The detail mapping is given below)
Unlikes	Discuss where the analog is unlike the scientific concept.	The analogy game was designed to resemble the actual structure of the atom largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Analog – Target Mapping

ANALOG	***ANALOG – FEATURES***	***TARGET- FEATURES***
The central circle	The card with the name, number of protons, and neutrons.	The nucleus containing protons, and neutrons of the atom.
The 1st outer concentric circle	A maximum of 2 students standing on the first circle.	Duplet rule – The first orbit can accommodate a maximum of 2 electrons.
The 2nd outer concentric circle	A maximum of 8 students standing on the second circle.	Octet rule - The second orbit can accommodate a maximum of 8 electrons.
The 3rd outer concentric circle	The remaining students were moved to the third outer circle. (only the atoms with electrons occupying the first 3 orbits were chosen).	Once the 1st and 2nd orbits have reached the maximum electronic configuration, the remaining electrons would fill in the 3rd orbit.
Completed 1st circle	Only 2 students are permitted to stay within the 1st circle.	The atom has attained complete and stable electronic configuration.
Completed 2nd circle	Only 8 students are permitted to stay within the 2nd circle..	The atom has attained complete and stable electronic configuration.
Incomplete 1st/2nd/3rd circles	Less than the maximum number that could be accommodated.	Incomplete/unstable electronic configuration.
Complete outermost circle	Maximum number of students filling up the circle.	Full valence shell/orbit. Stable electronic configuration.
If 1st/2nd/3rd circles are incomplete	If less number of students than the maximum that could be accommodated, students will move out or come in to complete the circle.	Can receive or give away electrons to attain a stable electronic configuration and get charged to form an ion or in some cases, the atoms share the electrons in the outer orbit.
Complete outer circle.	Two students filling up the 1st orbit, 8 students, if it is the second or third orbit.	There are elements, which have complete outer orbits, such as the inert gases, will neither give away nor receive electrons from any other atom.

Reflection

Conclusions	Was the analog clear and useful or confusing?	The students enjoyed the game. During analog-target mapping, the students brought up many likes and dislikes which listed on the board. They copied these points down (a copy has been attached on the following page. Later they were asked to answer a few questions and this tested their understanding thinking process. Many expressed that the game clarified a few of their uncertainties of the concept.
Improvements	Refocus as above in light of outcomes.	The analog will be refocused in the light of the above outcomes.

Action:

'Fill up the Orbit'- Rules of the An Analogy Game

The class was divided into two teams, 'Boys versus Girls' and a leader was chosen by each group. Two sets of four concentric circles were drawn on the floor as shown in Figure.3. The students were told that they were electrons, revolving around the nucleus in their orbits. The innermost circle represented the nucleus. A card containing the name of the element, its atomic number and mass was placed upturned inside the inner circle. When the teacher gave the 'start' signal, the students ran to the inner circle, flipped the card and read the data. They calculated the number of protons, neutrons and electrons of the element using the information and filled up the 'orbits' in consistence with the duplet and octet rules. The students of group, after filling the orbits with the required number, moved around in their respective circles once and the excess students moved out. Then, they sat down to show that they had completed the electron configuration. The leader had to call out whether they would give up or gain electrons to attain a stable electronic configuration. The game was deliberately organised as 'Boys versus Girls' to give a boost to the competitive spirit amongst the students. The open area under the library was chosen as the venue for the game. The class was marched off to the venue accompanied by a pre-service teacher. The students familiarised themselves with the layout. The students had two trials before they started the actual game, which was followed by a group discussion. During this time, each group clarified the rules of the game, which was essentially confirming the structure of the atom so that they could play the game 'correctly' and win. The trial was followed by six games with six different elements. The cards given to them are shown in Figure A.5.

Once the trials and six games were completed, ionic bonding was enacted by moving the girl who was occupying the outer orbit of Sodium atom to the outer orbit of the boys, which represented the Chlorine atom to form Sodium Chloride. Similar enacting showed the formation of an oxygen molecule. Difficulty was experienced by the students to show the sharing of electrons in covalent bonding and in the understanding the concept. Since the period ended at that time the class was dismissed and their doubts were clarified in the following session. The same two-tier test was administered on the following day during the science period and the answer papers were collected.

APPENDIX A. 3

‘Fill up the Orbit’- Diagrammatic representation

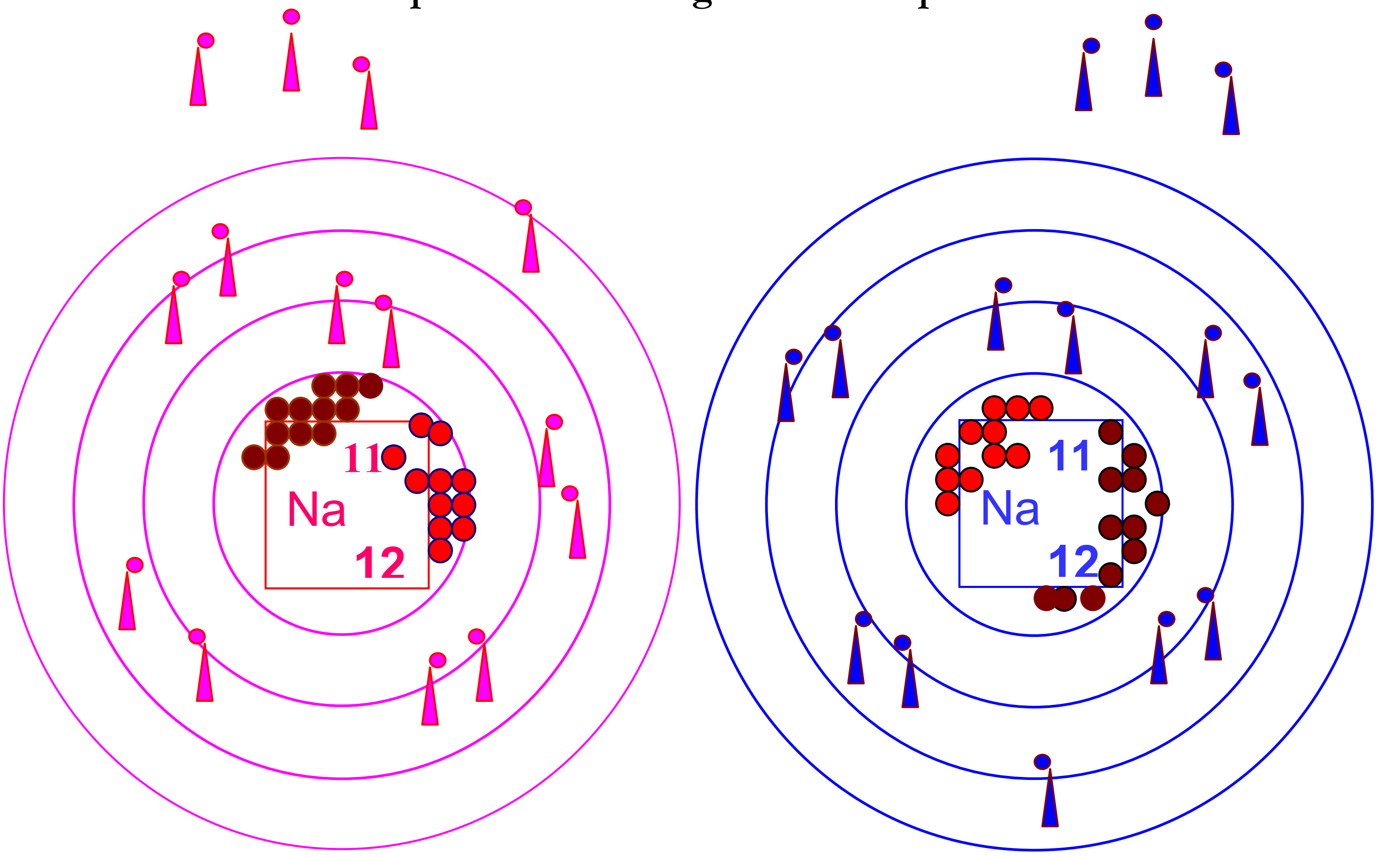


Figure A. 3 Fill up the orbit (An analogy - A game)

Legend:

Inner Circle: Nucleus, Circles: Orbits, Students: Electrons, Protons: , Neutrons:

GAME 1	GAME 2	GAME 3	GAME 4
O 8 16	Li 3 7	K 19 39	Ar 18 40
OXYGEN	LITHIUM	POTASSIUM	ARGON

GAME 5	GAME 6
Cl 17 35	N 7 14
CHLORINE	NITROGEN

Figure A. 4 Cards used in the game

APPENDIX A. 4

Figure A. 5 Fill up the Orbit – Girls: Focus and Planning

Figure A. 6 Fill up the Orbit – Boys: Filling up the orbits. . .

Figure A. 7 Filling up the orbits. . .

Figure A. 8 Filled up!

The FAR Guide: Reflection

During Reflection after the game, the students discussed various issues related to the game in class. Since the leader guided the team in the calculation of subatomic particles for each atom, and helped to fill the orbits with the correct number of 'electrons', a recommendation was made to change the leader after each game. The class felt that this would enable more students to know about atoms with minimum misconceptions.

APPENDIX A. 5

Two-Tier Diagnostic Instrument on the Understanding of Atoms and Molecules

Procedure and Instrumentation [based on the procedure described by Treagust (1986)]

What do you know about atoms and molecules?

What do you know about atoms and molecules?

The following pages contain 10 questions about atoms and molecules. Each question has two parts: A Multiple Choice Response followed by a Multiple Choice Reason. You are asked to make one choice from both the Multiple Choice Response section and one choice from the Multiple Choice Reason section for each question.

If you have another reason for your answer, write in the space provided as well as making the choice letter in the reason box.

Answer all questions on the separate answer sheet

1. Read each question carefully.
2. Take time to calculate and consider your answer.
3. Record your answer in the correct box on the answer sheet.

e.g. Q.5 $\boxed{2}$ Reason $\boxed{}$

4. Read the set of possible reasons for your answer.
5. Carefully select a reason, which best matches your thinking when you work out the answer.
6. Record your answer in the correct reason box on the Answer sheet.

e.g. Q. 5 $\boxed{}$ Reason $\boxed{C}$

7. If you change your mind about an answer, cross out the old answer and add the new choice.

e.g. Q. 5 $\boxed{}$ Reason $\boxed{\cancel{C}}$

8. If you wish to provide your own reason for the question, write your reason on the sheet in the space provided (d).

e.g. Q. 5 $\boxed{2}$ Reason d) ______________________________

Don't forget to record your name and other details on your Answer sheet.

What do you know about atoms and molecules?

Q.1. How would you describe an atom?
Your answer:
1) An atom is the smallest particle of a substance that cannot be broken down further.
2) An atom is the smallest particle of a substance that can be broken down further.
3) All elements are composed of tiny indivisible particles called atoms.
4) Any other answer: ____

The reason for your answer:
a) I cannot see atoms; therefore it must be very small and cannot be divided further.
b) Many particles join together to make elements and these particles can't be divided.
c) I cannot see atoms; therefore it must be very small, but it can be divided further.
d) Any other reason: ____

Q.2. When is an atom neutral?
Your answer:
1) When the atom has only neutrons.
2) When the electron number is equal to the neutron number.
3) When the electron number is equal to the proton number.
4) Any other answer: ____

The reason for your answer:
a) If the positive and negative charges of an atom are equal, an atom will be neutral.
b) If an atom has to be neutral, it should have only neutrons.
c) If the neutron number is equal to the electron number, the atom will be neutral.
d) Any other reason: ____

Q.3. Do you think that all the atoms of a particular element are identical (look and behave in the same manner)?
Your answer:
1) Yes, all the atoms of the same element are exactly alike.
2) No, the atoms of any one element are different from those of other elements.
3) Yes, a few atoms of the same element are very much alike.
4) Any other answer: ____

The reason for your answer:
a) An element sometimes can have atoms, which may be slightly different from the others.
b) An element is a pure substance; hence, all the atoms must be similar.
c) Atoms of all the gaseous elements look the same, but the atoms of liquids differ slightly.
d) Any other reason: ____

Q.4. What will you be looking at in atoms to say that they are identical?
1) The shape of the orbits.
2) The distribution of electrons.
3) The number of protons, electrons and neutrons.
4) Any other answer: ____

The reason for your answer:
a) The atoms will look the same, if the shapes of the orbits around the nuclei are identical.
b) The electron distribution should be the same, if the atoms are similar.
c) The numbers of the subatomic particles are the same if the atoms are similar.
d) Any other reason: ____

Q.5. What will happen if an atom loses an electron?

Your answer:
1. Nothing will happen, since this doesn't affect an atom.
2. The atom gets positively charged.
3. The atom gets negatively charged.
4. Any other answer: ____

The reason for your answer:
a) The electron is negatively charged; hence the atom becomes positive.
b) Losing one electron cannot change the charge of an atom.
c) The electron is negatively charged; hence the entire atom becomes negative.
d) Any other reason: ____

Q.6. What will happen if an atom gains an electron?

Your answer:
1. This doesn't affect an atom in any way.
2. The atom gets positively charged.
3. The atom gets negatively charged.
4. Any other answer: ____

The reason for your answer:
a) The electron is positively charged; hence the atom becomes positive.
b) Gaining one electron cannot change the charge of an atom.
c) The electrons are greater than the protons and the atom becomes negative.
d) Any other reason: ____

Q.7. Which electrons will move out of the orbit at first, if such a situation arises?

Your answer:
1) The electron/s closer to the nucleus will move out of the orbit at first.
2) All the electrons are capable of moving out, whenever they want.
3) The electron/s in the outermost orbit will move out of the orbit at first.
4) Any other answer: ____

The reason for your answer:
a) The outermost electrons have minimum attraction towards the protons in the nucleus.
b) The innermost shell has stronger force, hence they can jump out easily.
c) All the electrons have the same charge and they can move out at any time.
d) Any other reason: ____

Q.8 Why do atoms of the <u>same element</u> in some cases link up and stay together as a molecule?

Your answer:
1) Atoms of opposite kind are attracted together and stay together.
2) The atoms are neutral and this makes them stay together.
3) Some atoms share their electrons just to get stabilised and then, they stay together.
4) Any other answer: ____

The reason for your answer:
a) The atoms in an element are attracted to each other because they are of the same kind.
b) The atoms are placed closer to each other in an element causing links.
c) Bonds are established to attain a stable electronic configuration.
d) Any other reason: ____

Q.9 Why do atoms of <u>different elements</u> in some cases link up and stay together as a molecule?

Your answer:

1) Either to get a stable electronic configuration or attracted due to different charges in them.
2) Atoms of different elements have great attraction towards each other.
3) Atoms of different elements do not link up and stay together.
4) Any other answer: ____

The reason for your answer:

a) Similar attractive forces present in atoms can cause them to link up with each other.
b) There is no reason why atoms of different elements stay together.
c) Like charges repel and unlike charges attract.
d) Any other reason: ____

Q.10 Which one of the following is the heaviest of all?

$_{108}Ag^{47}$ (Silver) - represents an atom of Silver, which has 47 protons and 61 neutrons
$_{197}Au^{79}$ (Gold) - represents an atom of Gold, which has 79 protons and 118 neutrons
$_{64}Cu^{29}$ (Copper) - represents an atom of Copper, which has 29 protons and 35 neutrons

Your answer:

1) Silver
2) Gold
3) Copper

The reason for your answer:

a) If we arrange these in alphabetical order, Ag comes before Au, hence it must be heavier.
b) The atomic mass of Gold is greater then the others, hence it is heavier.
c) Copper has the least mass, hence it is heavier then the others.
d) Any other reason: ____

The end of paper

What do you know about atoms and molecules?
(Please complete all the details before you begin to answer the questions)

ANSWER SHEET

Name ________________________________ Class: __________

Date: _______________ Male: ___________ Female: __________ Age: _________

	ANSWER	REASON
1.	☐	☐
2.	☐	☐
3.	☐	☐
4.	☐	☐
5.	☐	☐
6.	☐	☐
7.	☐	☐
8.	☐	☐
9.	☐	☐
10.	☐	☐

Please copy **your own reason** here. (-only if you have written any on pages 2, 3 and 4)

1. ____________________________________
2. ____________________________________
3. ____________________________________
4. ____________________________________
5. ____________________________________
6. ____________________________________
7. ____________________________________
8. ____________________________________
9. ____________________________________
10. ____________________________________

What do you know about atoms and molecules?

ANSWER SHEET

Name ______________________________ Class: __________________________

Date: _______________ Male: ___________ Female: __________ Age: _____________

Q. 1 Answer	2	Q.1 Reason	c
Q. 2 Answer	3	Q.2 Reason	a
Q. 3 Answer	1	Q.3 Reason	b
Q. 4 Answer	3	Q.4 Reason	c
Q. 5 Answer	2	Q.5 Reason	a
Q. 6 Answer	3	Q.6 Reason	c
Q. 7 Answer	3	Q.7 Reason	a
Q. 8 Answer	3	Q.8 Reason	c
Q. 9 Answer	1	Q.9 Reason	c
Q. 10 Answer	2	Q.10 Reason	b

APPENDIX A. 6

Table 3. 2 Analysis of individual responses

	Concept - Atoms and Molecules	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.1	**How would you describe an atom?**			
Correct Answer	**2. An atom is the smallest particle of a substance that can be broken down further.**	34.78	21.74	-13.04
Alternate conception	1. An atom is the smallest particle of a substance that cannot be broken down further.	17.39	19.57	2.18
Alternate conception	3. All elements are composed of tiny indivisible particles called atoms.	47.83	58.70	10.87
Correct Reason	**c. I cannot see atoms; therefore it must be very small, but it can be divided further.**	32.61	56.52	23.91
Alternate conception	a. I cannot see atoms; therefore it must be very small and cannot be divided further.	15.22	13.04	-2.18
Alternate conception	b. Many particles join together to make elements and these particles can't be divided.	26.09	52.17	26.08
Misconception	Students' own	2.17	2.17	0
Q.No.2	**When is an atom neutral?**			
Correct Answer	**3. When the electron number is equal to the proton number.**	43.48	54.35	10.87
Misconception	1. When the atom has only neutrons.	8.70	4.35	-4.35
Alternate conception	2. When the electron number is equal to the neutron number.	43.48	39.13	-4.35
Misconception	Students' own	4.35	2.17	-2.18
Correct Reason	**a. If the positive and negative charges of an atom are equal, an atom will be neutral.**	63.04	69.57	6.53
Misconception	b. If an atom has to be neutral, it should have only neutrons.	8.70	6.52	-2.18
Alternate conception	c. If the neutron number is equal to the electron number, the atom will be neutral.	26.09	23.91	-2.18
Misconception	Students' own	2.17	0	-2.17
Q.No.3	**Do you think that all the atoms of a particular element are identical?**			
Correct Answer	**1. Yes, all the atoms of the same element are exactly alike.**	26.09	39.13	13.04
Alternate conception	2. No, the atoms of any one element are different from those of other elements.	39.13	30.43	-8.70
Alternate conception	3. Yes, a few atoms of the same element are very much alike.	34.78	30.43	-4.35
Correct Reason	**b. An element is a pure substance; hence, all the atoms must be similar.**	32.61	36.96	4.35
Alternate conception	a. An element sometimes can have atoms, which may be slightly different from the others.	43.48	52.17	8.69
Alternate conception	c. Atoms of all the gaseous elements look the same, but the atoms of liquids differ slightly.	23.91	10.87	-13.04

Question 1. How would you describe an atom?

Correct answer: An atom is the smallest particle of a substance that can be broken down further

Sixteen students chose the correct answer in the pretest, which dropped down to 10 in the posttest. During the interview and discussion, it was found that the students had difficulties in accepting that a small atom, invisible to the naked eye, could be broken down further. This is one of the reasons which contributed greatly to the decline of the average number of students who picked the correct answer, which went down by 13%.

Alternate conception 1: *An atom is the smallest particle of a substance that cannot be broken down further.*

This choice was selected by 8 (17%) students in the pretest and by 9 (20%) in the posttest, thus increasing the posttest average score for this alternate conception by 2 %. The explanation given for the anomaly for the above answer is applicable to this increase.

Alternate conception 2: *All elements are composed of tiny indivisible particles called atoms.*

This result reinforces the fact that the students found it difficult to believe that atoms are divisible due to their small size. 22 (48%) students chose this answer in the pretest and 27 (59%) in the posttest by increasing the average by 11%.

No other significant answers were given for this particular question. Later discussion proved that the size of atom made it almost impossible to believe that it could be broken down further. The students were given adequate explanation and taken to a higher level by explaining nuclear fission and fusion reactions, which was received with much interest. All the alternate conceptions were addressed in class subsequently.

Correct reason: I cannot see atoms; therefore it must be very small, but it can be divided further.

The posttest score decreased by 24% from the pretest. The only explanation could be, the more they learnt about the complexity of an atom, the more the reason for them to believe that such a complex 'nannobit' cannot be broken down.

Alternate conception 1: *I cannot see atoms; therefore it must be very small and cannot be divided further.*

Though this misconception showed a decrease in the posttest by 2%, 13% of the class still held this as an alternate conception, which was addressed later.

Alternate conception 2: *Many particles join together to make elements and these particles can't be divided.*

This percentage increase doubled in the posttest. It may be due to the students' lack of focus on the entire statement. They probably found the first part of the statement correct and ignored the last part. This alternate conception was held by 52% of the students and was clarified later.

Question 2. When is an atom neutral?

Correct answer: When the electron number is equal to the proton number.

This answer showed an increase of 10% in the posttest, indicating the positive effect of the analogy presented to them; 54% of the students believed that an atom is neutral, when the electron number is equal to the proton number. The acknowledgement that the atom would lose or gain electrons to attain a stable electronic configuration, resulting in a change in the charge was reinforced at the end of every game. This may have contributed to the understanding of charges.

Alternate conception: *When the electron number is equal to the neutron number.*

This is the only alternate conception held by 39% of the students. This misconception decreased by 4% in the posttest. Though many were sure that neutrons are not the only particles in an atom, they were not sure whether the neutrons in the nucleus have the ability to neutralize the charges held by the electrons.

Correct reason: *If the positive and negative charges of an atom are equal, an atom will be neutral.*

There was an increase of 7% in the posttest average for this answer and 69% of the students believed in this concept.

Alternate conception: *If the neutron number is equal to the electron number, the atom will be neutral*

Though this misconception decreased by 2% in the posttest, 11 students still held this alternate conception, which was discussed and the correct response was reinforced.

Question 3. Do you think that all the atoms of a particular element are identical (look and behave in the same manner)?

Correct answer: Yes, all the atoms of the same element are exactly alike.

There was an increase of 13% in the posttest indicating that the analogy helped.

Alternate conception 1: *Yes, a few atoms of the element are very much alike*

The posttest average showed a decrease of 4% but still there were 30% who failed to make an informed decision about the similarity of atoms in an element.

Alternate conception 2: *No, the atoms of any one element are different from those of other elements.*

The posttest showed a decrease of 8% but still there were 30% who believed this to be true, which was clarified during the posttest review.

Correct reason: *An element is a pure substance; hence, all the atoms must be similar.*

There was an increase of 4% in the posttest average for this answer and 37 % of the students believed in this concept.

Alternate conception 1: *An element sometimes can have atoms, which may be slightly different from the others.*

The students needed careful thinking before considering this reason. Strangely, the posttest average showed an increase of 9%. This point was clarified later.

Alternate conception 2: *Atoms of all the gaseous elements look the same, but the atoms of liquids differ slightly.*

The posttest average showed a decrease of 13% and the concept was clarified later..

Table 3. 2 Continued…	**Concept - Atoms and Molecules**	**Average %**		
		Pretest	**Posttest**	**Increase/ Decrease**
Q.No.4	**What will you be looking at in atoms to say that they are identical?**			
Correct Answer	**3. The number of protons, electrons and neutrons.**	**82.61**	**78.26**	**-4.35**
Alternate conception 1	1. The shape of the orbits.	4.35	10.87	6.52
Alternate conception	2. The distribution of electrons	13.04	10.87	-2.17
Correct Reason	**c. The numbers of the subatomic particles are the same if the atoms are similar.**	**58.70**	**76.09**	17.39
Misconception	a. The atoms will look the same, if the shapes of the orbits around the nuclei are identical.	13.04	8.70	-4.34
Concept	Atoms and Molecules	Pretest	Posttest	Difference
Alternate conception	b. The electron distribution should be the same, if the atoms are similar.	26.09	15.22	-10.87
Misconception	Students' own	2.17	0	-2.17
Q.No.5	**What will happen if an atom loses an electron?**			
Correct Answer	**2. The atom gets positively charged.**	**34.78**	**47.83**	13.05
Alternate conception 1	1. Nothing will happen, since this doesn't affect an atom.	19.57	10.87	-8.70
Alternate conception	3. The atom gets negatively charged.	41.30	34.78	-6.52
Misconception	Students' own	4.35	6.52	2.17

Table 3. 2 Continued…	**Concept - Atoms and Molecules**	**Average %**		
		Pretest	**Posttest**	**Increase/ Decrease**
Correct Reason	**a. The electron is negatively charged; hence the atom becomes positive.**	**41.30**	**52.17**	10.87
Alternate conception	b. Losing one electron cannot change the charge of an atom.	21.74	13.04	-8.70
Alternate conception	c. The electron is negatively charged; hence the entire atom becomes negative.	28.26	28.26	0
Misconception	Students' own	8.70	6.52	-2.18
Q.No.6	**What will happen if an atom gains an electron?**			
Correct Answer	**3. The atom gets negatively charged.**	**47.83**	**50.00**	2.17
Misconception	1. This doesn't affect an atom in any way.	10.87	8.70	-2.17
Alternate conception	2. The atom gets positively charged.	39.13	36.96	-2.17
Misconception	Students' own	2.17	4.35	2.18
Correct Reason	**c. The electrons are greater than the protons and the atom becomes negative.**	**43.48**	**50.00**	6.52
Alternate conception	a. The electron is positively charged; hence the atom becomes positive.	32.61	39.13	6.52
Misconception	b. Gaining one electron cannot change the charge of an atom.	19.57	6.52	-13.05
Misconception	Students' own	4.35	4.35	0

Concept	**Atoms and Molecules**	**Pretest**	**Posttest**	**Difference**
Q.No.7	**Which electrons will move out of the orbit at first, if such a situation arises?**			
Correct Answer	**3. The electron/s in the outermost orbit will move out of the orbit at first.**	**76.09**	**91.30**	15.21
Misconception	1. The electron/s closer to the nucleus will move out of the orbit at first.	6.52	4.35	-2.17
Misconception	2. All the electrons are capable of moving out, whenever they want.	17.39	2.17	-15.22
Misconception	Students' own	0	2.17	2.17
Correct Reason	a. The outermost electrons have minimum attraction towards the protons in the nucleus.	73.91	91.30	17.39
Misconception	b. The innermost shell has stronger force, hence they can jump out easily.	13.04	4.35	-8.69
Misconception	c. All the electrons have the same charge and they can move out at any time.	13.04	2.17	-10.87
Misconception	Students' own	0	2.17	2.17

Question 4. What will you be looking at in atoms to say that they are identical?

Correct answer: *The number of protons, electrons and neutrons.*

The average score decreased by 4%, i.e. two students changed the answer from correct to incorrect. When the students received the corrected pretest and posttest answer sheets, they were asked to identify the answers which were written correctly in the pretest, but answered wrongly in the posttest and give an explanation for doing so. The students identified this problem said that they guessed the correct answer while answering the pretest, but later, not sure of what to put in the posttest. A few others didn't know why they committed that mistake.

Alternate conception 1: *The shape of the orbits.*

Five students (11%) wrote that the shape of the orbits will tell them whether the atoms are identical or not. This was dealt with after the corrected answer papers were returned.

Correct reason: *The number of subatomic particles is the same if the atoms are similar*

The average score increased by 18% after the analogy game.

Alternate conception 1: *The electron distribution should be the same, if the atoms are similar.*

This does not answer the question, though the students could be easily misled by this answer. Though the average in the posttest showed a decrease by 10% for this response, 15% still held this view as an alternative conception.

Question 5. What will happen if an atom loses an electron?

Correct answer: *The atom gets positively charged.*

The posttest average showed an increase of 13% after the analogy game was played.

Alternate conception 1: *Nothing will happen to the atom, since this doesn't affect an atom.*

Though the posttest average showed a decrease of 8%, five students (10%) still held this alternative conception and this concept was clarified with an example later.

Alternate conception 2: *The atom gets negatively charged.*

34%, over one third, were not sure whether the atom would be positively or negatively charged. This was discussed and rectified after the answer papers were returned.

Correct reason: *The electron is negatively charged; hence the atom becomes positive.*

The average score increased by 10% after the analogy game was played.

Alternate conception 1: *Losing one electron cannot change the charge of an atom.*

8% believed that losing and electron will not change the charge of an atom and held this view as an alternate conception, which was clarified during revision later.

Alternate conception 2: *The electron is negatively charged; hence the entire atom becomes negative.*

28% believed in the above statement even after the analogy game, which had to be rectified later.

Question 6. What will happen if an atom gains an electron?

Correct answer: The atom gets negatively charged.

There was a marginal increase of 2.% in the posttest after the game was played.

Alternate conception 1: *The atom gets positively charged.*

37%, more than one third of the students, believed in the above statement and it was explained to them later.

Correct reason: The electrons are greater than the protons and the atom becomes negative.

There was an increase of 7% in the posttest after the analogy game was played.

Alternate conception 1: *The electron is positively charged; hence the atom becomes positive.*

Though there was a decrease of 7% in this misconception, 39% still believed that the electrons are positive in charge or were not sure of the charge and guessed it wrong.

Alternate conception 2: *Gaining one electron cannot change the charge of an atom.*

This misconception decreased by 13% after the analogy game was played.

Question 7. Which electrons will move out of the orbit at first, if such a situation arises?

Correct answer: The electron/s in the outermost orbit will move out of the orbit at first.

There was an increase of 15% in the posttest and 91% held this view.

Misconception: *The electron/s closer to the nucleus will move out of the orbit at first.*

This misconception was held by 4% of the cohort.

Misconception: *All the electrons are capable of moving out, whenever they want.*

It was interesting to note that there was a decrease in the above misconception by 15 % after the analogy was introduced.

Correct reason: *The outermost electrons have minimum attraction towards the protons in the nucleus.*

There was an increase of 17% after the analogy was introduced and 91% held this. conception. The reason could be that when the formation of a compound was 'enacted' in the game, a girl was moved to the boys' group to complete the orbit to attain a stable electronic configuration, which could have been the stimulus to retain this concept in memory. Two students had mentioned the name of the girl who was moved to the boys' group in their reflective comments.

Misconception: *All the electrons have the same charge and they can move out at any time*

Interestingly, this misconception was reduced by 11% and only one student had this misconception.

Table 3. 2 Continued…	**Concept - Atoms and Molecules**	**Average %**		
		Pretest	**Posttest**	**Increase/ Decrease**
Question. 8	**Why do atoms of the same element link up and stay together as a molecule?**			
Correct Answer	**3. Some atoms share their electrons just to get stabilised and then, they stay together.**	**58.70**	**60.87**	2.17
Alternate conception	1. Atoms of opposite kind are attracted together and stay together.	30.43	32.61	2.18
Misconception	2. The atoms are neutral and this makes them stay together.	10.87	6.52	-4.35
Correct Reason	**c. Bonds are established to attain a stable electronic configuration.**	**48.65**	**80.43**	31.78
Misconception	a. The atoms in an element are attracted to each other because they are of the same kind.	21.74	4.35	-17.39
Alternate conception	b. The atoms are placed closer to each other in an element causing links.	28.26	13.04	-15.22
Misconception	Students' own	4.35	2.17	-2.18
Question. 9	**Why do atoms of different elements link up and stay together as a molecule?**			
Correct Answer	**1. Either to get a stable electronic. Configuration/attracted due to different charges in them.**	**60.87**	**73.91**	13.04
Alternate conception	2. Atoms of different elements have great attraction towards each other.	28.26	21.74	-6.52
Misconception	3. Atoms of different elements do not link up and stay together.	10.87	4.35	-6.52
Correct Reason	**c. Like charges repel and unlike charges attract.**	**52.17**	**52.17**	0
Alternate conception	a. Similar attractive forces present in atoms can cause them to link up with each other.	36.96	36.96	0
Misconception	b. There is no reason why atoms of different elements stay together.	8.70	8.70	0
Misconception	Students' own	2.17	2.17	0

Table 3. 2 Continued…	Concept - Atoms and Molecules	Average %		
		Pretest	**Posttest**	**Increase/ Decrease**
Question. 10	**Which one of the following is the heaviest of all?**			
Correct Answer	**2. Gold**	39.13	93.48	54.35
Misconception	1. Silver	58.70	2.17	-56.53
Misconception	3. Copper	2.17	4.35	2.18
Correct Reason	**b. The atomic mass of Gold is greater then the others, hence it is heavier.**	39.13	95.65	56.52
Misconception	a. If we arrange these in alphabetical order, Ag comes before Au, hence it must be heavier.	58.70	0	-58.70
Misconception	c. Copper has the least mass, hence it is heavier then the others.	2.17	4.35	2.18

Question 8. Why do atoms of the same element in some cases link up and stay together as a molecule?

Correct answer: *Some atoms share their electrons just to get stabilised and then, they stay together.*

61%, about two thirds of the students held this concept after the analogy game was played and there was a marginal increase of 2% after the game.

Alternate conception: *Atoms of opposite kind are attracted together and stay together.*

Fifteen students (33%) chose the above answer; perhaps, due to negligence and failure to link the question and answer. The concept given above is a correct statement, but the atoms of the same element cannot have opposite charges to keep them together. This was explained to them after the answer papers were returned.

There were no other significant misconceptions or alternate conceptions.

Correct reason: *Bonds are established to attain a stable electronic configuration.*

There was an increase of 35% in the posttest average after the game and 80% agreed with this statement.

Misconception: *The atoms in an element are attracted to each other because they are of the same kind.*

The above misconception was reduced by 17% as shown by the posttest results. Only 2 students held this view after the analogy game was played.

Alternate conception: *The atoms are placed closer to each other in an element causing links.*

This misconception decreased by 17% in the posttest, but still 13% held this as an alternate conception Since the students were informed before the test that they must choose the best answer for the question, this vague answer was not accepted and was clarified with the students later.

Question 9. Why do atoms of <u>different elements</u> in some cases link up and stay together as a molecule?

Correct answer: *Either to get a stable electronic configuration or attracted due to different charges in them.*

There was an increase of 13% in the posttest average after the analogy game was played and 4% picked this choice in the posttest.

Alternate conception: *Atoms of different elements have great attraction towards each other.*

There was a decrease of 7% in the posttest average for this choice, but still, ten students (21%) considered the above as correct.

Correct reason: *Like charges repel and unlike charges attract.*

The average score in the pretest score remained unchanged.

Alternative conception: *Similar attractive forces present in atoms can cause them to link up.*

Seventeen students (36.96%) held this alternate conception, which indicated that it needed clarification. It was dealt with during the review of the answer papers.

Question 10: Which one of the following is the heaviest of all?

$_{108}Ag^{47}$ *(Silver) - represents an atom of Silver, which has 47 protons and 61 neutrons*

$_{197}Au^{79}$ *(Gold) - represents an atom of Gold, which has 79 protons and 118 neutrons*

$_{64}Cu^{29}$ *(Copper) - represents an atom of Copper, which has 29 protons and 35 neutrons*

Correct answer: *Gold*

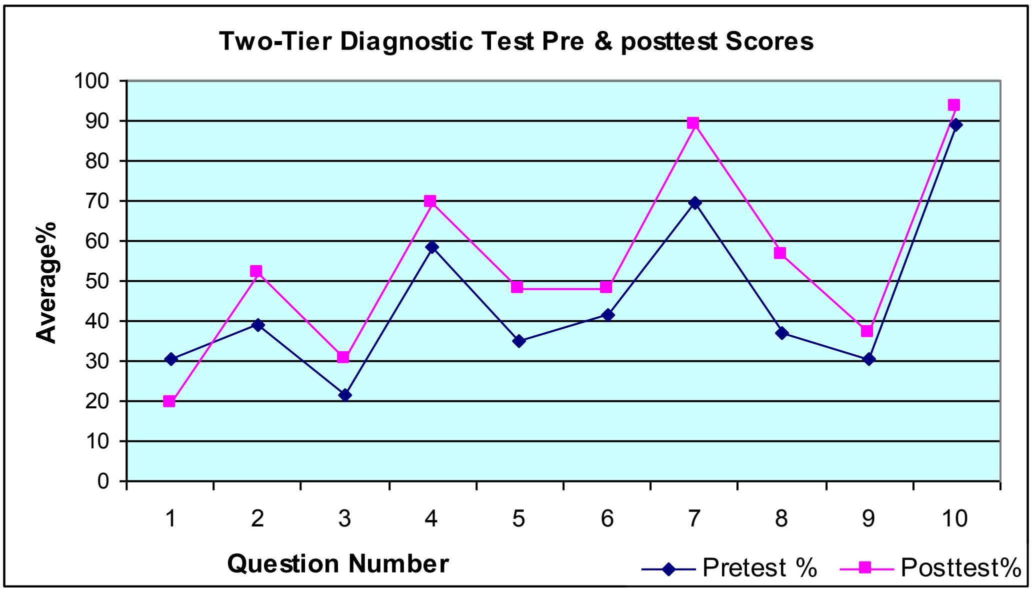
There was an increase of 54% in the posttest average after the analogy was introduced. 94% of the students believed that Gold is the heaviest of the three. This indicates that they are aware that the greater the atomic mass, the heavier the element would be.

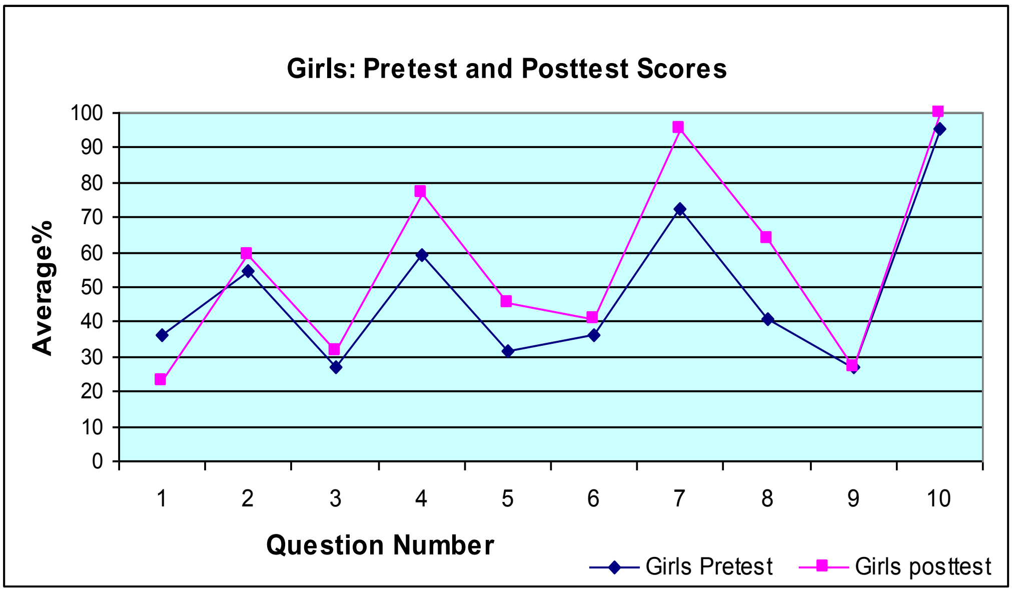
Misconception: 27 students identified Silver as the heaviest in the pretest, but changed to Gold except 1 student, thus decreasing the posttest average by 57% on this misconception.

Correct reason: *The atomic mass of Gold is greater then the others, hence it is heavier.*

96% chose the above reason and the posttest average showed an increase of 57% after playing the analogy game.

There were no other significant misconceptions or alternate conceptions noted.





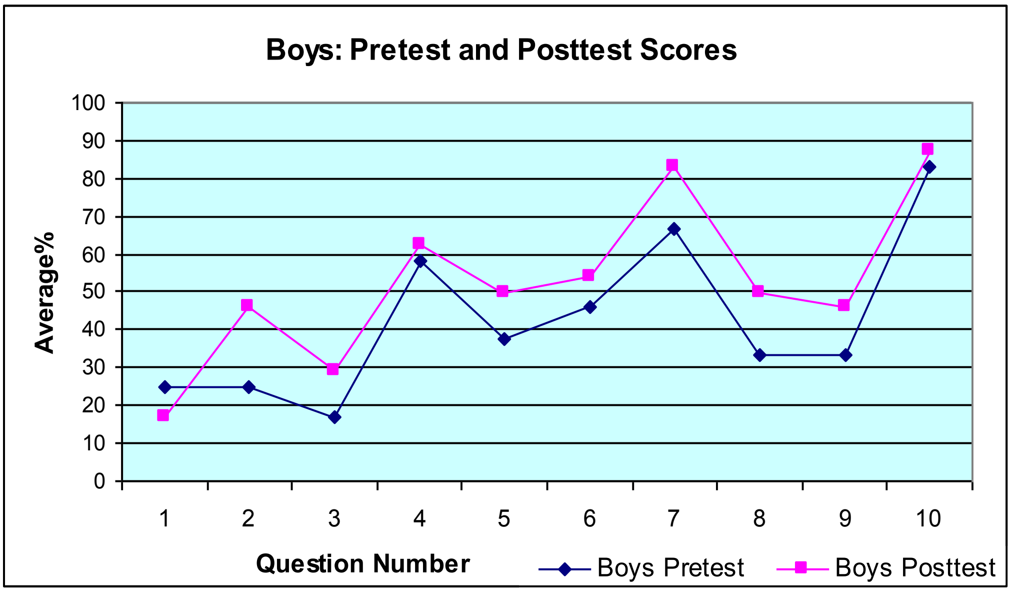
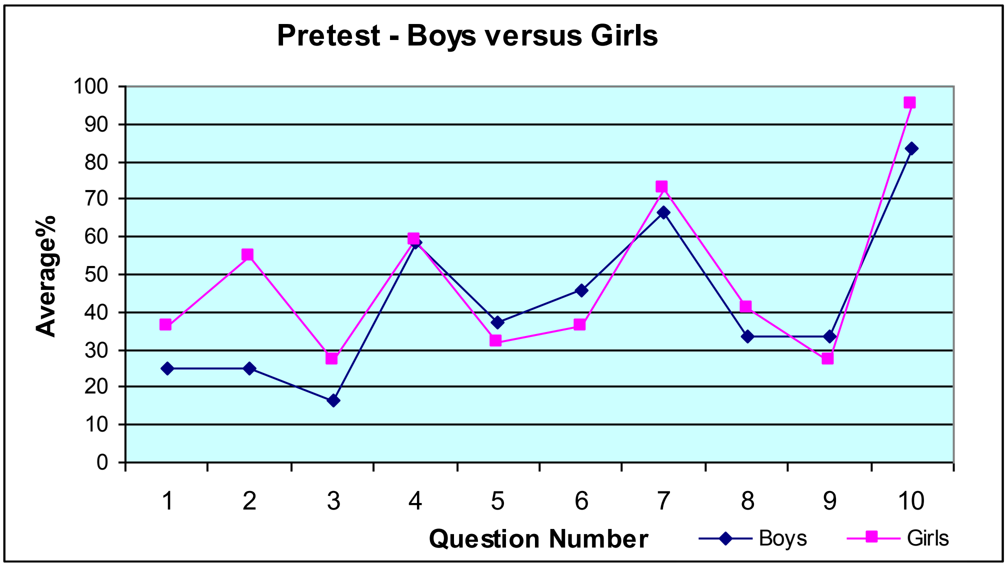


Figure B. 11 a. Graph: Class Results

APPENDIX A 7. d, e

Atoms and Molecules



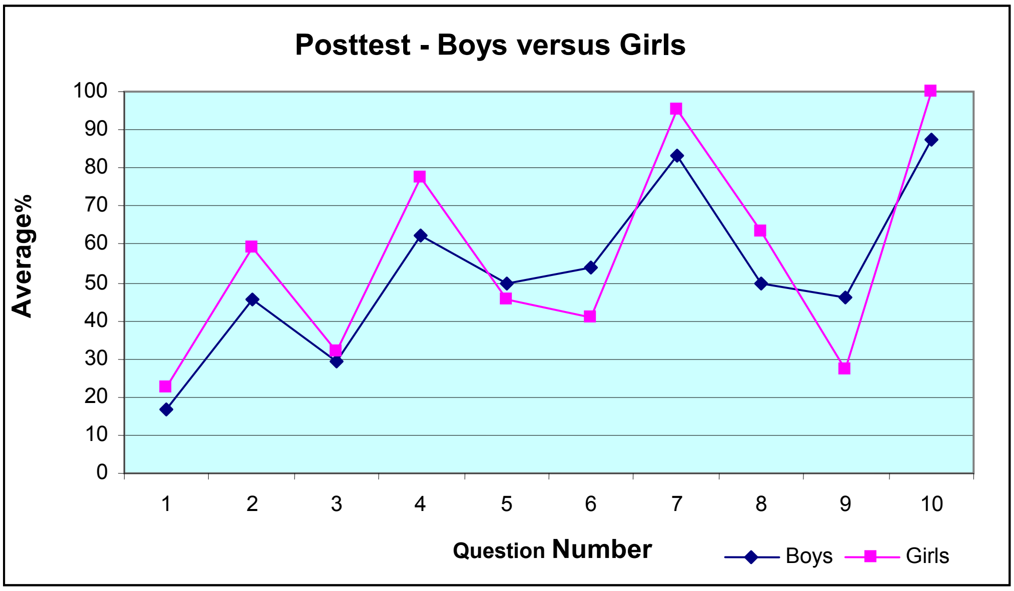


Figure A. 11 b. Graph: Gender Differences

APPENDIX A. 8

A Questionnaire

Review of the Analogy game

What do you know about atoms and molecules?

When you played this atom-analogy game, how did you figure out (understand) the:

1) Structure of an atom (the way it looks, what it is made of, etc):

____

____

____

2) The way an atom behaves in order to get a stable electronic arrangement:

____

____

____

3) Do you think that this analogy game will help you to remember the information about atoms <u>for a long time</u> to answer questions on atoms in higher classes? why?

____

____

____

4) Which **<u>one</u>** would you have preferred, the teacher teaching with an analogy or simply teaching the details of the atom?

____

____

____

5) Which one is more interesting, the analogy of soft drinks factory for cells or the atom-analogy game that we played today? Why?

____

____

APPENDIX A. 9

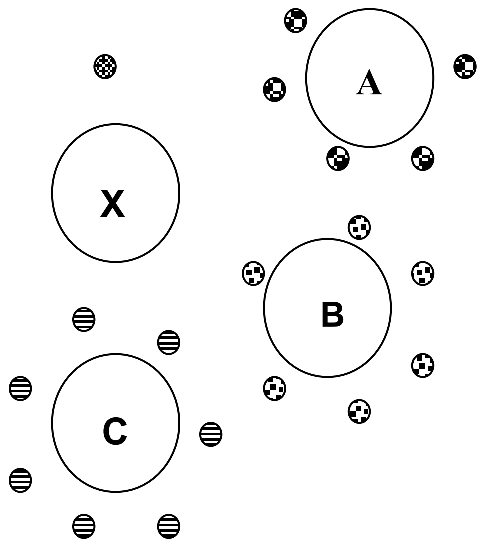
A Questionnaire to probe students' thinking process

NAME: DATE: F/M

You will be guided to answer the questions, but will not be helped to write the answers. Please write your own answer.

Q1. There are a few atoms of different elements; atom X with 1 electron <u>in the outermost orbit</u> and atoms A, B and C with, 5, 6 and 7 electrons respectively.

(Only the outermost orbit is shown in the picture)



Q1.

a. If X combines chemically to form a compound with one of these three atoms, which one would it be?

____

b. Your brain figured this out in a particular way: (i) What came to your mind at first?

____

____

____

(ii) What came to your mind next? ____

____

Q. 2. a. What was your 'thinking', when <u>you chose</u> your answer for Q. 1(or) what made you choose this particular answer)?

____

____

b. What was your 'thinking', when you decided <u>not to choose</u> the other two atoms as your answer for Q. 1?

____

____

Q. 3. Please write something more about how you answered Q.1 regarding what came first?

a) Circle your answer:

(i) Was that a <u>picture</u>, which came to your mind? Yes / No

(ii) Was that a <u>word or words</u> which was mentioned during the lesson, which came to your
mind? Yes / No

(iii) Was that the <u>game</u> we played, which came to your mind? Yes / No

(Go on to 'c', if it was 'word/s')

b) If your brain/mind brought out a picture:
(i) Was it the picture of the atom drawn on the board during the lesson? Yes / No
(ii) Was it the teacher explaining the structure of the atom drawn on the board during the lesson Yes / No
(iii) Was it the game played under the library? Yes / No
(Go on to 'd', if it was 'the game')

c) If your brain/mind brought out words:
(i) Was it about the atom written on the board during the lesson? Yes / No
(ii) Was it the teacher explaining the structure of the atom during the lesson? Yes / No
(iii) Was it the game played under the library? Yes / No

d) If your brain/mind brought up words, which part of the game did you remember to answer Q.1? Explain, please.

____

____

____

____

If you didn't answer any of Q.3, your answer could be:
Q. 4. 'I didn't visualise (see in your mind's eye) anything at all; I answered Q.1 simply by':

____

____

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____

____

Q. 5 I remember what I have learnt about the atom by:

____

____

____

____

____

Q. 6. Draw noble gas 'Y' using your own imagination. It must show at least 2 orbits. You may determine its atomic number and mass.

Summarising what we have learnt:

When you played this atom-analogy game, how did you figure out or understand the:

1) Structure of an atom (the way it looks, what it is made of, etc):

2) The way an atom behaves in order to get a stable electronic arrangement:

3) Do you think that this analogy game will help you to remember the information about atoms for a long time to answer questions on atoms in higher classes? Why do you think so?

4) Which **one** would you have preferred, the teacher teaching with an analogy or simply teaching the details of the atom?

APPENDIX A. 10

Statistical Analysis

Two-tier Diagnostic Testing - Atoms & Molecules: Frequencies

Pretest results

Item1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	32	69.6	69.6	69.6
	1	14	30.4	30.4	100.0
	Total	46	100.0	100.0	

Item2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	28	60.9	60.9	60.9
	1	18	39.1	39.1	100.0
	Total	46	100.0	100.0	

Item3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	36	78.3	78.3	78.3
	1	10	21.7	21.7	100.0
	Total	46	100.0	100.0	

Item4pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	19	41.3	41.3	41.3
	1	27	58.7	58.7	100.0
	Total	46	100.0	100.0	

Item5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	30	65.2	65.2	65.2
	1	16	34.8	34.8	100.0
	Total	46	100.0	100.0	

Item6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	27	58.7	58.7	58.7
	1	19	41.3	41.3	100.0
	Total	46	100.0	100.0	

Item7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	14	30.4	30.4	30.4
	1	32	69.6	69.6	100.0
	Total	46	100.0	100.0	

Item8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	29	63.0	63.0	63.0
	1	17	37.0	37.0	100.0
	Total	46	100.0	100.0	

Item9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	32	69.6	69.6	69.6
	1	14	30.4	30.4	100.0
	Total	46	100.0	100.0	

Item10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	5	10.9	10.9	10.9
	1	41	89.1	89.1	100.0
	Total	46	100.0	100.0	

Posttest results

Item1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	37	80.4	80.4	80.4
	1	9	19.6	19.6	100.0
	Total	46	100.0	100.0	

Item2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	22	47.8	47.8	47.8
	1	24	52.2	52.2	100.0
	Total	46	100.0	100.0	

Item3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	32	69.6	69.6	69.6
	1	14	30.4	30.4	100.0
	Total	46	100.0	100.0	

Item4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	14	30.4	30.4	30.4
	1	32	69.6	69.6	100.0
	Total	46	100.0	100.0	

Item5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	24	52.2	52.2	52.2
	1	22	47.8	47.8	100.0
	Total	46	100.0	100.0	

Item6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	24	52.2	52.2	52.2
	1	22	47.8	47.8	100.0
	Total	46	100.0	100.0	

Item7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	5	10.9	10.9	10.9
	1	41	89.1	89.1	100.0
	Total	46	100.0	100.0	

Item8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	20	43.5	43.5	43.5
	1	26	56.5	56.5	100.0
	Total	46	100.0	100.0	

Item9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	29	63.0	63.0	63.0
	1	17	37.0	37.0	100.0
	Total	46	100.0	100.0	

Item10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	3	6.5	6.5	6.5
	1	43	93.5	93.5	100.0
	Total	46	100.0	100.0	

TOTALpre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	3	6.5	6.5	6.5
	2	3	6.5	6.5	13.0
	3	9	19.6	19.6	32.6
	4	9	19.6	19.6	52.2
	5	7	15.2	15.2	67.4
	6	7	15.2	15.2	82.6
	7	6	13.0	13.0	95.7
	8	1	2.2	2.2	97.8
	9	1	2.2	2.2	100.0
	Total	46	100.0	100.0	

TOTALpost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	3	6.5	6.5	6.5
	3	8	17.4	17.4	23.9
	4	5	10.9	10.9	34.8
	5	6	13.0	13.0	47.8
	6	8	17.4	17.4	65.2
	7	8	17.4	17.4	82.6
	8	6	13.0	13.0	95.7
	9	2	4.3	4.3	100.0
	Total	46	100.0	100.0	

		Item1 pre	Item2 pre	Item3 pre	Item4 pre	Item5 Pre	Item6 pre	Item7 pre	Item8 pre	Item9 pre	Item10 pre
N	Valid	46	46	46	46	46	46	46	46	46	46
	Missing	0	0	0	0	0	0	0	0	0	0

		Item1 post	Item2 post	Item3 post	Item4 post	Item5 post	Item6 post	Item7 post	Item8 post	Item9 post	Item10 post
N	Valid	46	46	46	46	46	46	46	46	46	46
	Missing	0	0	0	0	0	0	0	0	0	0

APPENDIX B

(Relates to Chapter 4)

CELL STRUCTURE & FUNCTION

Page No

Appendix B. 1 a CELL AS A SOFT DRINK MANUFACTURING FACTORY

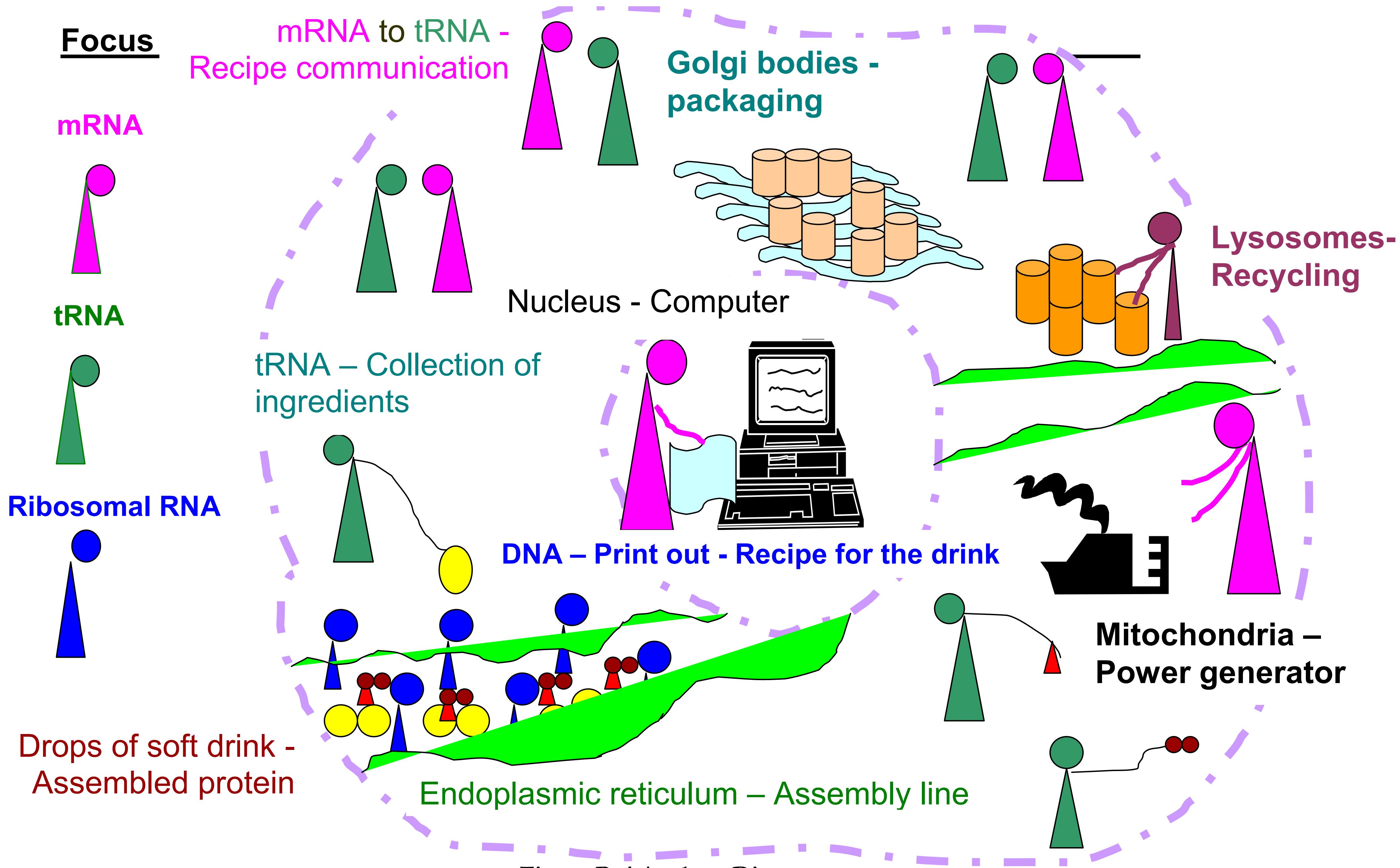


Figure B. 1 Analogy Diagram

Appendix B. 1. b

ANALOGY - A CELL AS A SOFT DRINKS BOTTLING FACTORY!

Table B. 1 Analog – Target Mapping – A Handout to students

ANALOG	ANALOG -FEATURES	TARGET
The building	A shed supported by beams, pipes, etc.	The cell supported by cytoskeleton.
Central computer	Contains all the information such as the recipe for the soft drink, names and quantity of the ingredients, details of processing, shipping and billing instructions, etc.	Nucleus contains the DNA, which in turn contains the codes for all the proteins to controls all the activities of the cell.
Computer print out	Contains the instructions to be followed in order to collect and blend what is needed.	DNA, which can readily give out the codes for assembling the needed protein.
Errand boy	Brings the instruction/message (recipe) from the computer room to the mixing area.	Messenger RNA from the nucleus to the cytoplasm bringing out the DNA code.
Stores Assistant	Reads the instruction and collects all the ingredients to manufacture what is needed.	Transfer RNA collects the needed amino acids as per the instruction.
Assembly line	Brewing, filtering and flavouring area of the plant	Endoplasmic reticulum, where the proteins are assembled.
Packaging group 1	Bottling the final product for local consumption.	Ribosomal RNA assembles the proteins to be used by the cell itself.
Packaging group 2	The packaged bottles are set up on a pallet and sent along conveyor belts to the appropriate truck at the loading dock.	Ribosomal RNA assembles the proteins to be used by other parts of the body.
Packaging group 3	Adding essences to enhance the flavour of the drink.	Golgi bodies gives finishing touches to the assembled protein such as adding a particular vitamin, perhaps.
Can recycler	The cans are crushed and recycled for further use.	Lysosomes release enzymes to break down organelles/substances for reuse.
Generator	Burns diesel and generates power for the factory.	Mitochondria oxidises food for energy.

Appendix B. 2 The FAR Guide for teaching and learning Cell Structure and Function

Focus

Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Cell –Structure and Function' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a soft drinks manufacturing factory.

Action

Likes	Discuss the features of analog and target. Draw similarities between them.	A cell could be compared to a soft drinks manufacturing factory, where each worker is responsible to carry out a particular function, exactly like the organelles of a cell (The details are given below).
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the actual structure and function of cells largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Similarities mapped out in detail (Given to students as a hand out)

ANALOG	ANALOG -FEATURES	TARGET
The building	A shed supported by beams, pipes, etc.	The cell supported by cytoskeleton.
Central computer	Contains all the information needed to regulate the activities in the factory; such as: recipe for the soft drink, names and quantity of the ingredients, details of processing, shipping and billing instructions, etc.	Nucleus contains the DNA, which has the codes for all the proteins to regulate the activities of the cell.
Computer print out	Contains instructions to collect and blend ingredients.	DNA gives codes for assembling the needed protein.
Errand boy	Brings the instruction (recipe) from the computer room to the mixing area.	Messenger RNA from the nucleus to the cytoplasm bringing out the DNA code.
Stores Assistant	Reads instruction and collects all the ingredients to manufacture the drink.	Transfer RNA collects needed amino acids as per code.
Assembly line	Brewing, filtering and flavouring area of the plant	Endoplasmic reticulum, where the proteins are assembled.
Packaging group 1	Bottling the final product for local consumption.	Ribosomal RNA assembling the proteins used by the cell.
Packaging group 2	The packaged bottles are set up on a pallet and sent along conveyor belts to the appropriate truck at the loading dock.	Ribosomal RNA assembling the proteins to be used by other parts of the body.
Packaging group 3	Adding essences to enhance the flavour of the drink.	Golgi bodies gives finishing touches to the assembled protein such as adding a particular vitamin, minerals, etc.
Can recycler	The cans are crushed and recycled for further use.	Lysosomes has enzymes to break down organelles for reuse.
Generator	Burns diesel and generates power for the factory.	Mitochondria oxidises food for energy.

Reflection

Conclusions	Was the analog clear and useful or confusing?	The analog seemed clear, useful, interesting and understandable. A few students requested for an electronic copy of the analogy picture. The students shared the differences between the analog and target with the class. The students give their own analogy for a cell. To confirm the students' understanding, their written opinions on the analog were collected and analysed for improvement.
Improvements	Refocus as above in light of outcomes.	The analogy will be refocused in the light of the above outcomes.

Focus

During this stage, the students concentrated on the visual of the cell analogy projected on the screen. They discussed the features of a soft drink factory and correlated its structure and functions with a cell and its organelles. (Appendix A shows the diagram).

Action

The students were given a hand out which contained the analog and target relationship. The students referred to the analog on the screen and related the structure to a cell. Different students were asked to relate and explain the analog-target relationship. The other students raised their view points on the same issue and displayed active participation. Then we went onto the analog-target mapping and brought out the similarities and differences. (Details included in Appendix A.2) At the end of the session, we summarised what we had learnt. A worksheet (Details included in Appendix A.3) was given to them during the following science lesson and the students were encouraged to complete the work sheet. Once the worksheet was completed, we decided to call out the analogies generated by the students, (which is a part of the worksheet given to them) so that the entire class can participate in discussion. The students had chances to stand up and explain whether the student generated analogies were appropriate or not when compared with a cell. The students who generated the analogy were asked to explain why and how they considered their analog it to be appropriate to relate to a cell.

Reflection

During this stage, the students and I discussed the opinions on the analogs and targets; also matters relating to learning scientific concepts using an analogy.

Appendix B. 3

Two-Tier Diagnostic Instrument on the Understanding of Cells

Procedure and Instrumentation [based on the procedure described by Treagust (1986)]

What do you know about cells?

The following pages contain 10 questions about atoms and molecules. Each question has two parts: A Multiple Choice Response followed by a Multiple Choice Reason. You are asked to make one choice from both the Multiple Choice Response section and one choice from the Multiple Choice Reason section for each question.

If you have another reason for your answer, write in the space provided as well as making the choice letter in the reason box.

Answer all questions on the separate answer sheet

1. Read each question carefully.
2. Take time to calculate and consider your answer.
3. Record your answer in the correct box on the answer sheet.

e.g. Q.5 | 2 | Reason | |

4. Read the set of possible reasons for your answer.
5. Carefully select a reason, which best matches your thinking when you work out the answer.
6. Record your answer in the correct reason box on the Answer sheet.

e.g. Q. 5 | | Reason | C |

7. If you change your mind about an answer, cross out the old answer and add the new choice.

e.g. Q. 5 | | Reason | ~~C~~ |

8. If you wish to provide your own reason for the question, write your reason on the sheet in the space provided (d).

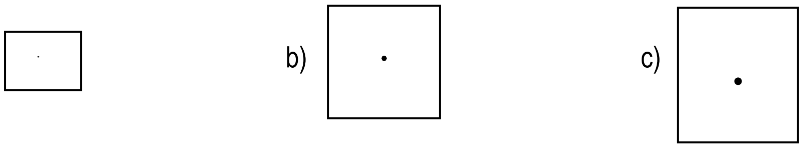
e.g. Q. 5 | 2 | Reason d) ________________________________

Don't forget to record your name and other details on your Answer sheet.

What do you know about cells?

Question 1. Estimate the number of cells in each dot in the squares.

1. a) b) c)



Your answer:

1) Approximately hundred cells in (a), about five hundred cells in (b) about a few thousands in (c)
2) Approximately 10 cells in (a), 30 cells in (b) and 100 cells in (c).
3) All these are too small to contain even one cell.
4) **Any other or your own answer:**

The reason for choosing the above answer: When I wrote this answer, my thought/s were:

a) If a cell is that small, it can't function the way we learnt in class in producing energy, producing substances and in performing such complex functions.
b) A cell could be small and yet functions effectively to keep one alive.
c) Cells are not that important, but the body is.
d) **Any other reason for your answer**:

Question 2. Why don't I see any cells in a piece of meat?
Your answer:

1) Meat is made of cells, which are so small, that it is not visible to our naked eyes.
2) Meat is not made of cells
3) Meat is chunky and not divided into small units.
4) Any other or your own answer:

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:

a) Meat and cells are entirely different things and we can't find cells in meat.
b) There are cells in animals, not necessarily in a piece of meat.
c) The cells are there, but I am unable to see it with my naked eye.
d) **Any other reason for your answer**:

Question 3. What is the importance of cells in living organisms?
Your answer:

1. Cells are becoming more and more important in cell research.
2. Cells are important because they don't allow the living to die.
3. Cells give a structure to all the living and carry out various functions.
4 **Any other or your own answer:**

The reason for choosing the above answer: When I wrote this answer, my thought/s were:

a) All living organisms are made of cells and this keeps them alive.
b) Cells must be important because they are big and make up the human body.
c) Cells protect all the living organisms from diseases.
d) **Any other reason for your answer**

Question 4. How do cells give you energy for all your daily activities?
Your answer:
1) My body produces energy to do work, not my cells.
2) The cells receive food and oxygen from blood and oxidise to produce energy.
3) The cells are too small to produce energy for any of my activities.
4) Any other or your own answer:
____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) My cells can't produce energy; only my body has the required materials to produce energy.
b) The digested food and oxygen can pass through the blood vessels into the cells to produce energy.
c) To produce the energy that I need for my activities, I need something bigger than these small cells.
d) **Any other reason for your answer**: ____

Question 5. Which part of the cell produces energy for your daily activities?
Your answer:
1. Nucleus
2. Golgi bodies
3. Mitochondrion (mitochondria-plural)
4. **Any other or your own answer:**
____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) Nucleus, being the most important part of the cell, produces energy for the cell.
b) Mitochondrion has the ability to produce energy.
c) Golgi bodies are piled up to generate energy.
d) **Any other reason for your answer**:
____

Question 6. How do the cells your body <u>work together</u> in keeping you alive?
Your answer:
1) The cells must be communicating with each other constantly by sending out substances.
2) The cells need not work together to keep me alive.
3) We have many organ systems to coordinate the activities of the various cells in our body.
4) **Any other or your own answer:**

____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) The cells in my body can secrete many substances to keep me alive.
b) I have a body with different parts which function on their own to keep me alive.
c) My brain and a few other organs coordinate and enable my cells to work together.
d) Any other reason for your answer:
____

Question 7. How does the nucleus communicate with the rest of the organelles in the cell?
Your answer:
1) The mitochondria send messages through the DNA molecules and control all the activities of the cell.
2) The DNA molecules in the nucleus give out coded messages by sending messenger RNA into the cytoplasm.
3) The ER membranes pass on the messages from the nucleus to the other organelles.
4) **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Mitochondrion is the powerhouse, which has the power to send messages to control all the activities.
b) The DNA has the instructions or codes for the messages, which control all the activities of the cell.
c) ER membranes are continuous tubes through which messages can pass easily to the organelles.
d) **Any other reason for your answer**:
____

Question 8. Can we manipulate the cells and change them to our advantage?
Your answer:
1) Yes, it is possible to make changes in cells.
2) We cannot change a cell, because such manipulation will kill the cells.
3) The cells are so small and the organelles are even smaller; we cannot change anything in them.
4) **Any other or your own answer:**____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) The cells are very small and this makes it impossible to make changes.
b) Scientists have changed cells successfully.
c) Changes can be made in the organs (e.g. work out to improve muscles),but cells can't be changed.
d) **Any other reason for your answer**: ____

Question 9. If you expect a change in the offspring of an organism, which part of the cell would you target?
Your answer:
1) Golgi bodies
2) Gene
3) Endoplasmic reticulum
4) Any other or your own answer:____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) Changes in genes will change the codes, which control the development of the offspring.
b) Golgi bodies can produce substances and make changes in the offspring.
c) Endoplasmic reticulum can produce different substances to bring out a change in the offspring.
d) **Any other reason for your answer**: ____

Question 10. Do you think that the cells in plants and animals are functionally similar?
Your answer:
1) They are not similar because the plants are not living organisms.
2) They both can't be similar because plants are different from animals.
3) Both plants and animals exhibit a number of similarities between their cells.
4) **Any other or your own answer:** ____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
b) The plants cannot have feelings like animals and they don't move around.
c) They have to be similar because both are in living organisms.
d) There are no chromosomes and genes in plants.
e) **Any other reason for your answer:** ____

What do you know about cells?

ANSWER SHEET

Name ______________________________ Class: ________________________

Date: ______________ Male: __________ Female: _________ Age: __________________

Q. 1 Answer	☐	Q.1 Reason	☐
Q. 2 Answer	☐	Q.2 Reason	☐
Q. 3 Answer	☐	Q.3 Reason	☐
Q. 4 Answer	☐	Q.4 Reason	☐
Q. 5 Answer	☐	Q.5 Reason	☐
Q. 6 Answer	☐	Q.6 Reason	☐
Q. 7 Answer	☐	Q.7 Reason	☐
Q. 8 Answer	☐	Q.8 Reason	☐
Q. 9 Answer	☐	Q.9 Reason	☐
Q. 10 Answer	☐	Q.10 Reason	☐

What do you know about cells?

ANSWER SHEET (CORRECT ANSWERS)

Name ______________________________ Class: ____________________

Date: ______________ Male: __________ Female: _________ Age: ______________)

Q. 1. Answer	2	Q.1. Reason	b
Q. 2. Answer	1	Q.2. Reason	c
Q. 3. Answer	3	Q.3. Reason	a
Q. 4. Answer	2	Q.4. Reason	b
Q. 5. Answer	3	Q.5. Reason	b
Q. 6. Answer	1	Q.6. Reason	c
Q. 7. Answer	2	Q.7. Reason	b
Q. 8. Answer	1	Q.8. Reason	b
Q. 9. Answer	2	Q.9. Reason	a
Q. 10. Answer	3	Q.10. Reason	c

APPENDIX B. 4

Table B. 4 Analysis of Individual Responses

	Concept - Cell	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.1	**Estimate the number of cells in each dot in the squares.**			
Correct Answer	**2. Approximately 10 cells in (a), 30 cells in (b) and 100 cells in (c).**	18.42	21.05	-2.63
Misconception	1. Approximately hundred cells in (a), about five hundred cells in (b) and about a few thousands in (c)	76.32	76.32	0
Misconception	3. All these are too small to contain even one cell.	0	2.63	2.63
Correct Reason	**b. A cell could be small and yet functions effectively to keep one alive.**	89.47	89.47	0
Misconception	a. If a cell is that small, it can't function the way we learnt in class in producing energy, substances and in performing such complex functions.	2.63	7.89	5.26
Misconception	c. Cells are not that important, but the body is	2.63	0	-2.63
Misconception	Students' own	5.26	2.63	-2.63
Q.No.2	**Why don't I see any cells in a piece of meat?**			
Correct Answer	**1. Meat is made of cells, which are so small, that it is not visible to our naked eyes.**	78.95	86.84	7.89
Misconception	2. Meat is not made of cells	13.16	7.89	-5.27
Misconception	3. Meat is chunky and not divided into small units.	7.89	5.26	-2.63
Correct Reason	**c. The cells are there, but I am unable to see it with my naked eye.**	81.58	84.21	2.63
Misconception	a. Meat and cells are entirely different things and we can't find cells in meat.	2.63	0	-2.63
Misconception	b. There are cells in animals, not necessarily in a piece of meat	13.16	13.16	0
Q.No.3	**What is the importance of cells in living organisms?**			
Correct Answer	**3. Cells give a structure to all the living and carry out various functions.**	76.32	81.58	5.26
Misconception	1. Cells are becoming more and more important in cell research.	10.53	2.63	-7.9
Misconception	2. Cells are important because they don't allow the living to die.	10.53	15.79	5.26
Misconception	Students' own	2.63	0	-2.63
Correct Reason	**a. All living organisms are made of cells and this keeps them alive.**	65.79	63.16	2.63
Misconception	b. Cells must be important because they are big and make up the human body.	10.53	5.26	-5.27
Misconception	c. Cells protect all the living organisms from diseases.	21.05	31.58	10.53
Misconception	Students' own	2.63	0	-2.63

Q. 1 Estimate the number of cells in each dot in the squares.

Correct answer: 2. Approximately 10 cells in (a), 30 cells (b) and 100 cells in (c).

This is an introductory question and was included to know the students' understanding of cells with regard to their approximate size. The presented analogy did not assist in learning this concept, but the fact remains that the knowledge of the sizes of cells plays a significant role in understanding cells in relation to the vital processes they perform. Only 21% of the students could guess the sizes of the cells in each box.

1. Approximately hundred cells in (a), about five hundred cells in (b) and about a few thousands in (c)

This alternate conception was held by 76% of the students. This had to be clarified and reinforced with examples.

3. All these are too small to contain even one cell.

This is a misconception held by 3% of the students.

Correct reason: b. A cell could be small and yet functions effectively to keep one alive.

This is an analogy related question which was correctly answered by 89% of the students, which shows that the analogy enhanced student-understanding of the concept.

a. If a cell is that small, it can't function the way we learnt in class in producing energy, substances and in performing such complex functions.

c. Cells are not that important, but the body is.

The above two misconceptions were held by a negligible number of students.

Q.2. Why don't I see any cells in a piece of meat?

Correct answer: 1. Meat is made of cells, which are so small, that it is not visible to our naked eyes.

The average score rose by 8% after the analogy was introduced and the class average in the posttest was 87%. This indicates that the majority were aware that living organisms are made of cells.

2. Meat is not made of cells.

3. Meat is chunky and not divided into small units.

Only 8% and 5% of the students held the misconception (2) and (3) respectively in the posttest and these were taken up for discussion during the posttest review and clarified.

Correct reason: c. The cells are there, but I am unable to see it with my naked eye.

84% of the students chose the above to confirm their knowledge of the above concept.

a. Meat and cells are entirely different things and we can't find cells in meat.

b. There are cells in animals, not necessarily in a piece of meat.

The above alternative conceptions held by 13% of the students who believed that meat and cells are separate entities, even after the analogy was presented.

Q.3 What is the importance of cells in living organisms?

Correct answer: 3. Cells give a structure to all the living and carry out various functions.

Posttest results showed that 82%,of the students, an increase of 5% from the pretest, believed that cells are the structural and functional unit of life.

1. Cells are becoming more and more important in cell research.

The above two misconception was held by 3% of the students. Though this is negligible, it was taken up for discussion during the posttest review and clarified.

2. Cells are important because they don't allow the living to die.

This is a typical example of how students can easily construct misconceptions while the teacher's aim is to assist in understanding. The cell was introduced with an example in order to capture the attention of the students and to simplify the concept. A situation was created to show how we 'catch' cold, if one student in the class was infected with a cold virus and if he was not hygienic in his dealings. This must have had a strong impact on student thinking. The students felt that if a cell is 'programmed' to protect us from a cold virus, 'It does not allow us to die'. The same idea is reflected in the reason 'c'.

Correct reason: a. All living organisms are made of cells and this keeps them alive.

This correct answer showed a decrease of 3% in the posttest. As explained earlier, there was a shift in student thinking and this lost percentage was added to reason 'c'.

b. Cells must be important because they are big and make up the human body.

This misconception was held by 5% of the students.

c. Cells protect all the living organisms from diseases.

Due to the initial presentation of linking cells with viral infection, 32% of the students remembered cells in association with diseases rather than with the vital processes.

Table B. 2 Continued…	Concept - Cell	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.4	**How do cells give you energy for all your daily activities?**			
Correct Answer	**2. The cells receive food and oxygen from blood and oxidise to produce energy.**	94.74	97.37	2.63
Misconception	1. My body produces energy to do work, not my cells.	0	0	0
Misconception	3. The cells are too small to produce energy for any of my activities.	5.26	2.63	-2.63
Correct Reason	**b. The digested food and oxygen can pass through the blood vessels into the cells to produce energy.**	92.11	94.74	2.63
Misconception	a. My cells can't produce energy; only my body has the required materials to produce energy.	5.26	2.63	-2.63
Misconception	c. To produce the energy that I need for my activities, I need something bigger than these small cells.	0	2.63	2.63

Q. 4. How do cells give you energy for all your daily activities?

Correct answer: 2. The cells receive food and oxygen from blood and oxidise to produce energy.

The posttest results showed that 97% of the students were aware that the blood distributes food and oxygen to the cells in the body the energy comes from the oxidation of the food.

1.My body produces energy to do work, not my cells.

It is interesting to note that none of the students chose this choice and they were able to distinguish between the body and cells.

3. The cells are too small to produce energy for any of my activities.

This misconception was held by only 3% of the students and was clarified later in class.

Correct reason: b. The digested food and oxygen can pass through the blood vessels into the cells to produce energy.

This reason was chosen by 95% of the students, which supports view that those who chose the correct answer knew why they chose that particular choice.

a. My cells can't produce energy; only my body has the required materials to produce energy.

c. To produce the energy that I need for my activities, I need something bigger than these small cells.

The above two misconceptions were held by about 5% of the students and were clarified later.

Table B. 2 Continued . . .	Concept - Cell	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.5	**Which part of the cell produces energy for your daily activities?**			
Correct Answer	**3. Mitochondrion (mitochondria-plural)**	47.37	65.79	18.42
Alternate conception	1. Nucleus	38.64	23.68	-14.96
Alternate conception	2. Golgi bodies	15.79	10.53	-5.26
Correct Reason	**b. Mitochondrion has the ability to produce energy.**	44.74	65.79	21.05
Alternate conception	a. Nucleus, being the most important part of the cell, produces energy for the cell.	31.58	18.42	-13.16
Alternate conception	c. Golgi bodies are piled up to generate energy.	21.05	13.16	-7.89
Q.No.6	**How do the cells your body work together in keeping you alive?**			
Correct Answer	**1.The cells must be communicating with each other constantly by sending out substances.**	63.16	78.95	15.79
Misconception	2. The cells need not work together to keep me alive.	7.89	0	-7.89
Alternate conception	3. We have many organ systems to coordinate the activities of the various cells in our body.	26.32	21.05	-5.27
Misconception	4. Students' own	2.63	0	-2.63
Correct Reason	**a. The cells in my body can secrete many substances to keep me alive.**	55.26	60.53	5.27
Misconception	b. I have a body with different parts which function on their own to keep me alive.	13.16	5.26	-7.9
Alternate conception	c. My brain and a few other organs coordinate and enable my cells to work together.	31.58	31.58	0
Q.No.7	**How does the nucleus communicate with the rest of the organelles in the cell?**			
Correct Answer	**2. The DNA molecules in the nucleus give out coded messages by sending messenger RNA into the cytoplasm.**	57.89	92.11	34.22
Misconception	1. The mitochondria send messages through the DNA molecules and control all the activities of the cell.	21.05	7.89	-13.16
Misconception	3. The ER membranes pass on the messages from the nucleus to the other organelles.	18.42	0	-18.42
Misconception	4. Students' own	2.63	0	-2.63
Correct Reason	**b. The DNA has the instructions or codes for the messages, which control all the activities of the cell.**	60.53	76.32	15.79
Alternate conception	a. Mitochondrion is the powerhouse, which has the power to send messages to control all the activities.	21.05	21.05	0
Misconception	c. ER membranes are continuous tubes through which messages can pass easily to the organelles.	15.79	0	-15.79
Misconception	d. Students' own	2.63	2.63	0

Q. 5. Which part of the cell produces energy for your daily activities?

Correct answer: 3. Mitochondrion (mitochondria-plural)

Only 66% of the students of the students believed that mitochondria were the organelles, which helped to release the energy from the food. The posttest results showed an increase of 18% in the average obtained by the students.

1. Nucleus

Since the students were aware that the nucleus is an important organelle for the cell, they assigned this function to the nucleus. This alternate conception held by 24% of the students was taken up during the review of the posttest and the doubts were clarified.

2. Golgi bodies

This alternate conception was held by 11% of the students and this was reviewed and the essential points were reinforced after the posttest.

Correct reason: b. Mitochondrion has the ability to produce energy.

There was an increase of 21% in the posttest after the presentation of the analogy. All the students who knew that mitochondria perform this function had chosen this reason to show their knowledge base for this answer.

c. Golgi bodies are piled up to generate energy.

This misconception was held by 13% of the students despite 8% decrease after the analogy was presented. This was further discussed during the review of the posttest and the correct reason was reinforced further.

a. Nucleus, being the most important part of the cell, produces energy for the cell.

Though this alternate conception was reduced by 13% after the analogy was presented, was still held by 18% of the students. This was further discussed to clear the students' misunderstanding during the review of the posttest.

Q. 6. How do the cells your body <u>work together</u> in keeping you alive?

Correct answer: 1.The cells must be communicating with each other constantly by sending out substances.

This is a higher order thinking question, requiring flexibility in thinking to consider the whole picture, which was answered by 79% of students correctly in the posttest, an increase of 16% from the pretest. The analogy picture showed different coloured figures representing the three kinds of RNA particles and these figures interact while passing the template for the proteins, collection of amino acids and so on. Arriving at this answer needed further thinking as to how these organelles could possibly communicate.

2. The cells need not work together to keep me alive.

It is interesting to note that none believed that this is possible after the presentation of the analogy, though 8% had chosen this answer in the pretest.

3. We have many organ systems to coordinate the activities of the various cells in our body.

This alternate conception was held by 21% of the students even after the presentation of the analogy. The students seem to forget that the body organs are made of cells. It has been observed that the students find it convenient to swap between the functions of organelles and organs when they are not clear in their understanding.

Correct reason: a. The cells in my body can secrete many substances to keep me alive.

This answer was chosen by 61% of the students in the posttest, showing an increase of 5% from the pretest.

b. I have a body with different parts which function on their own to keep me alive.

This is a misconception held by 5% of the students.

c. My brain and a few other organs coordinate and enable my cells to work together.

This alternative conception is held by 32% of the students and this confusion remains as a persisting problem. The students were aware that our brain exercises control by coordinating the various parts and functions of our body. They also knew that the nucleus exercises control and coordinate cellular and body functions. The clarity of these concepts seemed lacking and had to be taught once again starting from the levels of organisation in an organism, so that they would remember that individual cells are responsible for the production of specific proteins under the instruction of the nucleus, more specifically the DNA particles and the outcome of which has tremendous influence on the cellular and body functions.

Q.7. **How does the nucleus communicate with the rest of the organelles in the cell?**

Correct answer: 2. The DNA molecules in the nucleus give out coded messages by sending messenger RNA into the cytoplasm.

An increase of 34% in the posttest from the pretest shows that the students were benefited from the presentation of the analogy. 92% answered correctly.

1. The mitochondria send messages through the DNA molecules and control all the activities of the cell.

There was a decrease of 14% in the average of this misconception in the posttest, indicating that the analogy was beneficial in reducing this misconception.

3. The ER membranes pass on the messages from the nucleus to the other organelles.

After the presentation of the analogy, this misconception was completely removed from this cohort. The decrease in this misconception was brought down by 18%.

Correct reason: b. The DNA has the instructions or codes for the messages, which control all the activities of the cell.

An increase of 16% after the presentation of the analogy brought the posttest average to 76% indicating that the analogy helped in understanding and retention.

a. Mitochondrion is the powerhouse, which has the power to send messages to control all the activities.

This misconception held by the 16% of the students was completely removed after the presentation of the analogy.

c. ER membranes are continuous tubes through which messages can pass easily to the organelles.

This alternate conception was held by 16% of the students. During the review after the posttest this was explained to the students.

Table B. 2 Continued. . .	**Concept - Cells**	**Average %**		
		Pretest	**Posttest**	**Increase/ Decrease**
Question. 8	**Can we manipulate the cells and change them to our advantage?**			
Correct Answer	**1. Yes, it is possible to make changes in cells.**	21.05	44.74	23.69
Alternate conception	2. We cannot change a cell, because such manipulation will kill the cells.	44.74	39.47	-5.27
Alternate conception	3. The cells are so small and the organelles are even smaller; we cannot change anything in them.	34.21	15.79	-18.42
Correct Reason	**b. Scientists have changed cells successfully.**	18.42	42.11	23.69
Alternate conception	a. The cells are very small and this makes it impossible to make changes.	31.58	21.05	-10.53
Alternate conception	c. Changes can be made in the organs (e.g. work out to improve muscles),but cells can't be changed.	44.74	36.84	-7.9
Misconception	d. Students' own	5.26	0	-5.26
Question. 9	**If you expect a change in the offspring of an organism, which part of the cell would you target?**			
Correct Answer	**2. Gene**	71.05	89.47	18.42
Misconception	1. Golgi bodies	15.79	5.26	-10.53
Misconception	3. Endoplasmic reticulum	13.16	5.26	-7.9

Table B. 2 Continued	Concept - Cells	Average %		
		Pretest	Posttest	Increase/ decrease
Correct Reason	**a. Changes in genes will change the codes, which control the development of the offspring.**	73.68	89.47	15.79
Misconception	b. Golgi bodies can produce substances and make changes in the offspring.	10.53	5.26	-5.27
Misconception	c. Endoplasmic reticulum can produce different substances to bring out a change in the offspring.	10.53	5.26	-5.27
Question. 10	**Do you think that the cells in plants and animals are functionally similar?**			
Correct Answer	**3. Both plants and animals exhibit a number of similarities between their cells.**	81.58	71.05	**-10.53**
Misconception	1. They are not similar because the plants are not living organisms.	7.89	5.26	-2.63
Alternate conception	2. They both can't be similar because plants are different from animals.	10.53	21.05	**10.52**
Misconception	4. Students' own	0	2.63	**2.63**
Correct Reason	**c. They have to be similar because both are in living organisms.**	63.16	65.79	2.63
Misconception	a. The plants cannot have feelings like animals and they don't move around.	5.26	0	-5.26
Alternate conception	b. There are no chromosomes and genes in plants.	15.79	18.42	**2.63**
Alternate conception	d. Students' own	15.79	15.79	0

Q.8. Can we manipulate the cells and change them to our advantage?

1. Yes, it is possible to make changes in cells.

Though the posttest average showed an increase of 24% increase after the presentation of the analogy, the posttest average was only 48%. A detailed description of certain current cytotechniques such as the recombinant DNA technology and the Human genome project were explained to the students after the posttest to enhance their understanding on the manipulation of cells.

2. We cannot change a cell, because such manipulation will kill the cells.

This misconception was reduced by 5% in the posttest average, but still held by 39%. The remedial measure taken for the whole cohort has been described above.

3. The cells are so small and the organelles are even smaller; we cannot change anything in them.

This is an inherent problem associated with abstract concepts. A few students find it difficult to understand when the object and processes cannot be visualised. In my experience, the concepts associated with very small entities such as atoms and cells and cellular processes such as chromosomal crossing over, protein synthesis are generally difficult for the students to understand

Correct reason: b. Scientists have changed cells successfully.

Though the average score in the posttest showed an increase of 24% after the presentation of the analogy, only 42% of students were aware that scientists have manipulated cells.

a. The cells are very small and this makes it impossible to make changes.

This concept was held as an alternative conception by 21% of the students, though there was a 11% decrease in the posttest average. The size of the cell seemed to matter while considering the manipulation of cells. Many students considered it impossible to tamper with the cell organelles due to their microscopic size.

c. Changes can be made in the organs (e.g. work out to improve muscles), but cells can't be changed.

This alternate conception was held by 37% of the cohort and was dealt with in great detail as explained earlier for Q.8.1.

Q. 9. If you expect a change in the offspring of an organism, which part of the cell would you target?

2. Gene

The posttest average showed an increase of 18% after the presentation of the analogy and 89% of the cohort chose the correct answer for this question.

1. Golgi bodies

This misconception showed a decrease of 11% in the posttest average.

3. Endoplasmic reticulum

This misconception decreased by 8% after the presentation of the analogy.

Correct reason: a. Changes in genes will change the codes, which control the development of the offspring.

This choice was selected by 89% of the students in the posttest, an increase of 16% from the pretest average.

b. Golgi bodies can produce substances and make changes in the offspring.

c. Endoplasmic reticulum can produce different substances to bring out a change in the offspring.

The above two misconceptions decreased by 5% in the posttest, but were still held by 5% of the cohort.

Q.10. Do you think that the cells in plants and animals are functionally similar?

3. Both plants and animals exhibit a number of similarities between their cells.

The analogy did not have any direct bearing on this concept. This question tested the students' ability to transfer what was learnt for the animal cells to the plant cells. Strangely, the posttest average was 11% less than the pretest for this particular answer. The correct answer was chosen by 71% of the cohort. This indicates that the students needed help to understand that plants are living organisms, just like the animals.

1. They are not similar because the plants are not living organisms.

The posttest score showed a decrease of 3%. This misconception was held by 5 % of the cohort.

2. They both can't be similar because plants are different from animals.

This alternate conception was held by 21% as indicated by the posttest score. This point was taken up and discussed in the class during the posttest review.

Correct reason: c. They have to be similar because both are in living organisms.

This reason was chosen by 66% of the students and there was only a marginal increase in posttest score.

a. The plants cannot have feelings like animals and they don't move around.

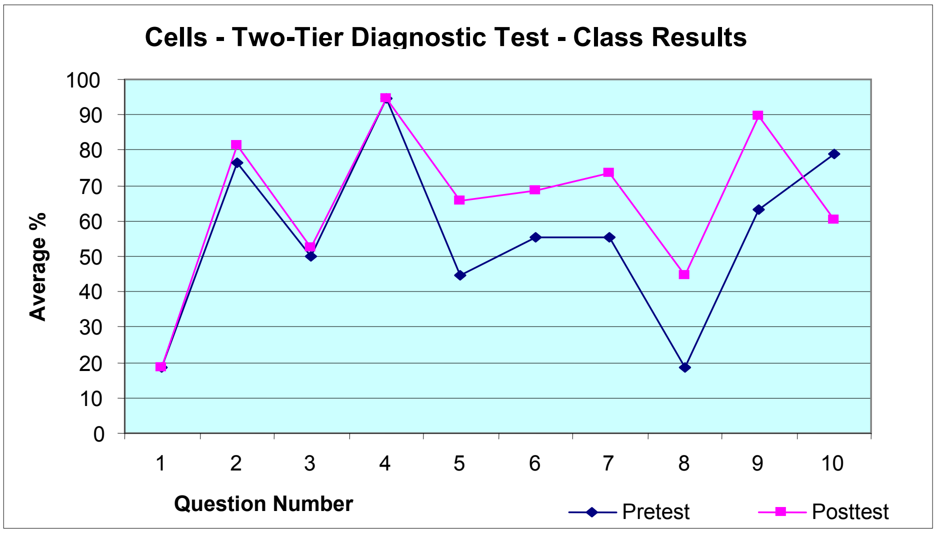
None of the students agreed with the above misconception.

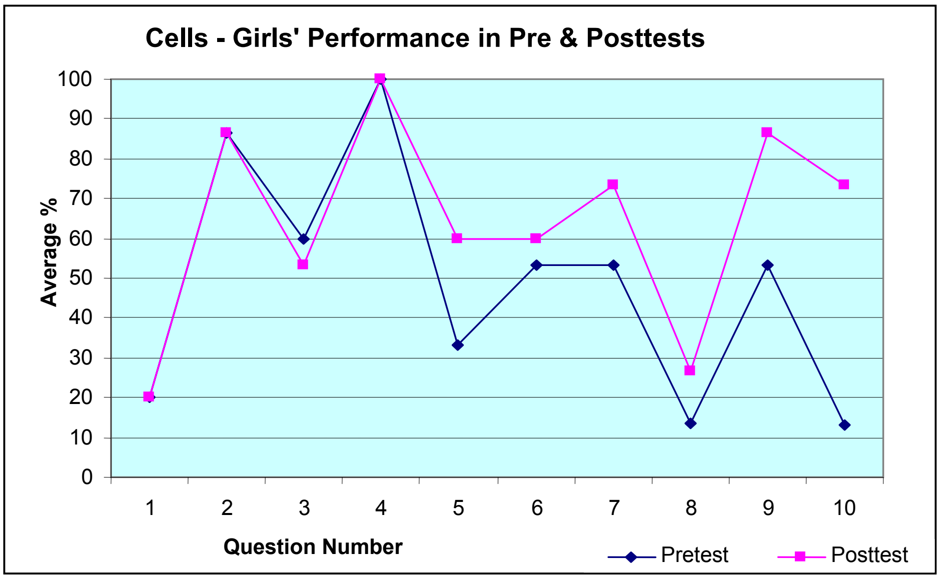
b. There are no chromosomes and genes in plants.

There was an increase of 3% in the posttest average and this alternate conception was held by 18% of the students and was clarified later..

Appendix B. 5 a, b, c

Cell - Structure and Function





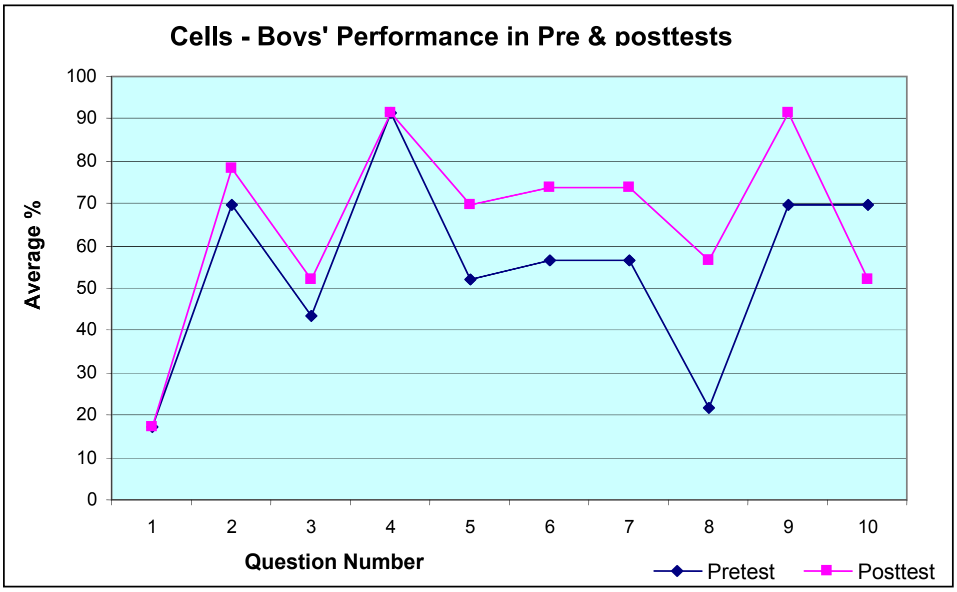
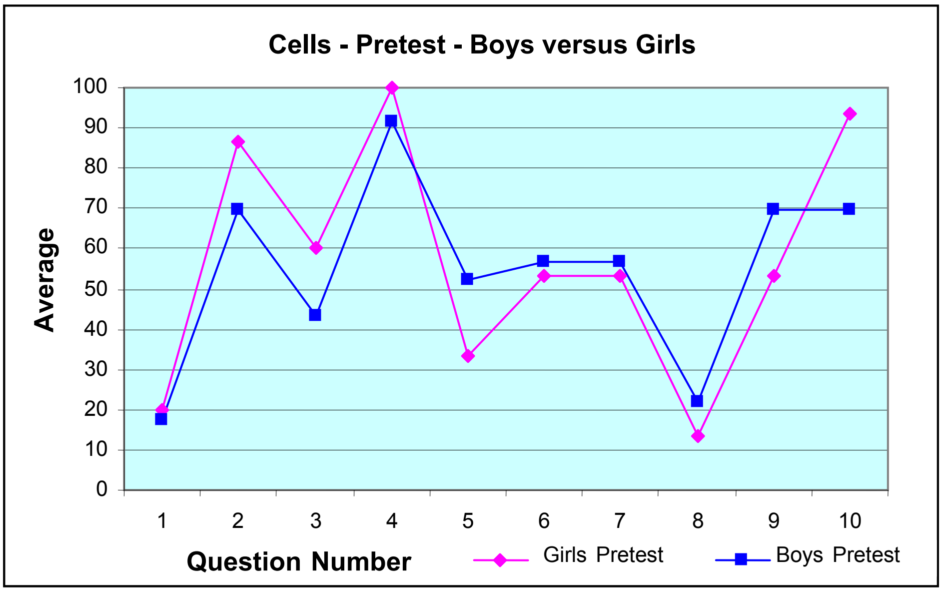


Figure B 3 a. Graph: Class Results

APPENDIX B. 5 d. e

Cell Structure and Function



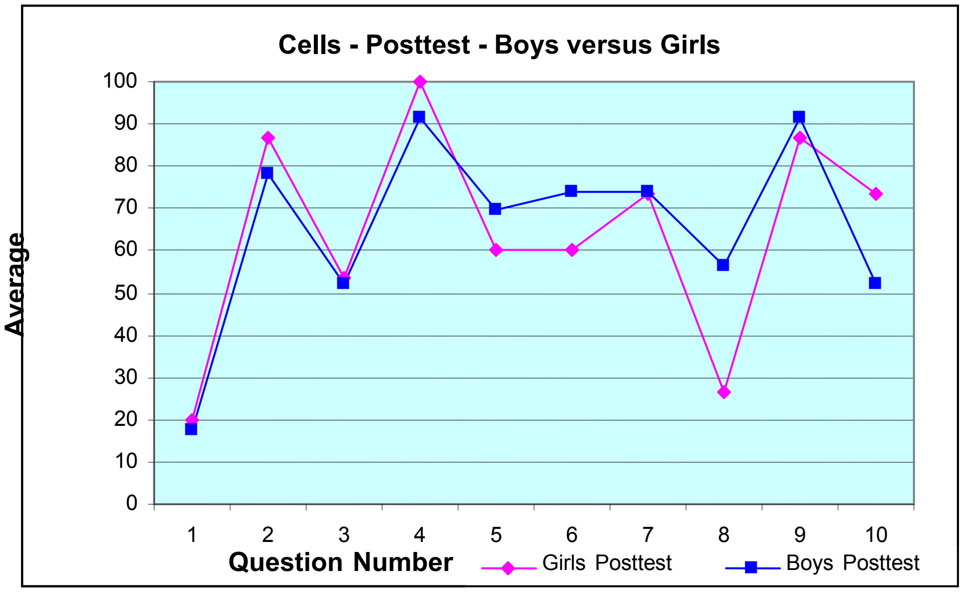


Figure B. 3. b Graph: Gender Differences

Appendix B. 6

A Questionnaire - Analog - Target Relationship

A cell and a soft drink manufacturing factory

1. You are given a familiar example to help you to understand a concept. The example is known as an **analog** (e.g. factory) and the comparison or the association that you relate to this analog is known as the **target** (e.g. cell).

Complete the following table to show the analog-target relationship. The first one has been done for you:

ANALOG	TARGET
Factory	Cell

.

2. Your brain might bring up another analogy of your own, which helps you to understand the parts and functions of cell organelles better.

Your target: **Cell** Your own **Analog**: ______________________________

ANALOG	TARGET

There may be a few things in your analogy, which is not like a cell. Can you list them and explain briefly?

My analogy	Organelle	Why/where it is not like the cell in my body

Do you think that the analogy helped you to understand the study of cell better? If so, explain.

Appendix B. 7 		# Frequencies: Cell Analogy

		Q1pre	Q2pre	Q3pre	Q4pre	Q5pre	Q6pre	Q7pre	Q8pre	Q9pre	Q10pre
N	Valid	38	38	38	38	38	38	38	38	38	38
	Missing	0	0	0	0	0	0	0	0	0	0

Frequency Table

Q1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	2.6	2.6	2.6
	1b	26	68.4	68.4	71.1
	1c	1	2.6	2.6	73.7
	1d	1	2.6	2.6	76.3
	2b	7	18.4	18.4	94.7
	4b	1	2.6	2.6	97.4
	4d	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1c	29	76.3	76.3	76.3
	1d	1	2.6	2.6	78.9
	2a	1	2.6	2.6	81.6
	2b	4	10.5	10.5	92.1
	3b	1	2.6	2.6	94.7
	3c	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

Q3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	5.3	5.3	5.3
	1b	1	2.6	2.6	7.9
	1c	1	2.6	2.6	10.5
	2a	4	10.5	10.5	21.1
	3a	19	50.0	50.0	71.1
	3b	3	7.9	7.9	78.9
	3c	7	18.4	18.4	97.4
	4d	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q4pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2b	35	92.1	92.1	92.1
	2d	1	2.6	2.6	94.7
	3a	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

Q5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	12	31.6	31.6	31.6
	1b	1	2.6	2.6	34.2
	1d	1	2.6	2.6	36.8
	2c	6	15.8	15.8	52.6
	3b	16	42.1	42.1	94.7
	3c	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

Q6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	21	55.3	55.3	55.3
	1b	1	2.6	2.6	57.9
	1c	2	5.3	5.3	63.2
	2b	2	5.3	5.3	68.4
	2c	1	2.6	2.6	71.1
	3b	2	5.3	5.3	76.3
	3c	8	21.1	21.1	97.4
	4c	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	7	18.4	18.4	18.4
	1d	1	2.6	2.6	21.1
	2a	1	2.6	2.6	23.7
	2b	21	55.3	55.3	78.9
	3b	1	2.6	2.6	81.6
	3c	6	15.8	15.8	97.4
	4b	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	7	18.4	18.4	18.4
	1d	1	2.6	2.6	21.1
	2a	4	10.5	10.5	31.6
	2c	12	31.6	31.6	63.2
	2d	1	2.6	2.6	65.8
	3a	8	21.1	21.1	86.8
	3c	5	13.2	13.2	100.0
	Total	38	100.0	100.0	

Q9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	2.6	2.6	2.6
	1b	4	10.5	10.5	13.2
	1d	1	2.6	2.6	15.8
	2a	26	68.4	68.4	84.2
	2d	1	2.6	2.6	86.8
	3a	1	2.6	2.6	89.5
	3c	4	10.5	10.5	100.0
	Total	38	100.0	100.0	

Q10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	2.6	2.6	2.6
	1b	2	5.3	5.3	7.9
	2a	1	2.6	2.6	10.5
	2d	3	7.9	7.9	18.4
	3b	4	10.5	10.5	28.9
	3c	24	63.2	63.2	92.1
	3d	3	7.9	7.9	100.0
	Total	38	100.0	100.0	

Frequencies

		Q1post	Q2post	Q3post	Q4post	Q5post	Q6post	Q7post	Q8post	Q9post	Q10post
N	Valid	38	38	38	38	38	38	38	38	38	38
	Missing	0	0	0	0	0	0	0	0	0	0

Frequency Table

Q1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	5.3	5.3	5.3
	1b	27	71.1	71.1	76.3
	2a	1	2.6	2.6	78.9
	2b	7	18.4	18.4	97.4
	4d	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	1	2.6	2.6	2.6
	1c	31	81.6	81.6	84.2
	1d	1	2.6	2.6	86.8
	2b	3	7.9	7.9	94.7
	3b	1	2.6	2.6	97.4
	3c	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	2.6	2.6	2.6
	2a	4	10.5	10.5	13.2
	2b	1	2.6	2.6	15.8
	2c	1	2.6	2.6	18.4
	3a	19	50.0	50.0	68.4
	3b	1	2.6	2.6	71.1
	3c	11	28.9	28.9	100.0
	Total	38	100.0	100.0	

Q4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2b	36	94.7	94.7	94.7
	2c	1	2.6	2.6	97.4
	3a	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	7	18.4	18.4	18.4
	1c	1	2.6	2.6	21.1
	1d	1	2.6	2.6	23.7
	2c	4	10.5	10.5	34.2
	3b	25	65.8	65.8	100.0
	Total	38	100.0	100.0	

Q6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	23	60.5	60.5	60.5
	1b	1	2.6	2.6	63.2
	1c	5	13.2	13.2	76.3
	1d	1	2.6	2.6	78.9
	3b	1	2.6	2.6	81.6
	3c	7	18.4	18.4	100.0
	Total	38	100.0	100.0	

Q7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	7.9	7.9	7.9
	2a	5	13.2	13.2	21.1
	2b	29	76.3	76.3	97.4
	2d	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

Q8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	16	42.1	42.1	42.1
	1c	1	2.6	2.6	44.7
	2a	5	13.2	13.2	57.9
	2c	10	26.3	26.3	84.2
	3a	3	7.9	7.9	92.1
	3c	3	7.9	7.9	100.0
	Total	38	100.0	100.0	

Q9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	2	5.3	5.3	5.3
	2a	34	89.5	89.5	94.7
	3c	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

Q10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	1	2.6	2.6	2.6
	1c	1	2.6	2.6	5.3
	2b	3	7.9	7.9	13.2
	2c	2	5.3	5.3	18.4
	2d	3	7.9	7.9	26.3
	3b	3	7.9	7.9	34.2
	3c	21	55.3	55.3	89.5
	3d	3	7.9	7.9	97.4
	4c	1	2.6	2.6	100.0
	Total	38	100.0	100.0	

	Q1pre	Q2pre	Q3pre	Q4pre	Q5pre	Q6pre	Q7pre	Q8pre	Q9pre	Q10pre
Mean	.1842	.7632	.5000	.9211	.4211	.5526	.5526	.1842	.6842	.6316
Std. Deviation	.39286	.43085	.50671	.27328	.50036	.50390	.50390	.39286	.47107	..48885

Frequencies

Frequency Table

ItQ1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	31	81.6	81.6	81.6
	1.00	7	18.4	18.4	100.0
	Total	38	100.0	100.0	

ItQ2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	9	23.7	23.7	23.7
	1.00	29	76.3	76.3	100.0
	Total	38	100.0	100.0	

ItQ3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	19	50.0	50.0	50.0
	1.00	19	50.0	50.0	100.0
	Total	38	100.0	100.0	

ItQ4Pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	3	7.9	7.9	7.9
	1.00	35	92.1	92.1	100.0
	Total	38	100.0	100.0	

ItQ5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	22	57.9	57.9	57.9
	1.00	16	42.1	42.1	100.0
	Total	38	100.0	100.0	

ItQ6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	17	44.7	44.7	44.7
	1.00	21	55.3	55.3	100.0
	Total	38	100.0	100.0	

ItQ7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	17	44.7	44.7	44.7
	1.00	21	55.3	55.3	100.0
	Total	38	100.0	100.0	

ItQ8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	31	81.6	81.6	81.6
	1.00	7	18.4	18.4	100.0
	Total	38	100.0	100.0	

ItQ9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	12	31.6	31.6	31.6
	1.00	26	68.4	68.4	100.0
	Total	38	100.0	100.0	

ItQ10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	14	36.8	36.8	36.8
	1.00	24	63.2	63.2	100.0
	Total	38	100.0	100.0	

Frequencies

Frequency Table

ItQ1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	31	81.6	81.6	81.6
	1.00	7	18.4	18.4	100.0
	Total	38	100.0	100.0	

ItQ2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	7	18.4	18.4	18.4
	1.00	31	81.6	81.6	100.0
	Total	38	100.0	100.0	

ItQ3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	19	50.0	50.0	50.0
	1.00	19	50.0	50.0	100.0
	Total	38	100.0	100.0	

ItQ4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	2	5.3	5.3	5.3
	1.00	36	94.7	94.7	100.0
	Total	38	100.0	100.0	

ItQ5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	13	34.2	34.2	34.2
	1.00	25	65.8	65.8	100.0
	Total	38	100.0	100.0	

ItQ6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	15	39.5	39.5	39.5
	1.00	23	60.5	60.5	100.0
	Total	38	100.0	100.0	

ItQ7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	9	23.7	23.7	23.7
	1.00	29	76.3	76.3	100.0
	Total	38	100.0	100.0	

ItQ8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	22	57.9	57.9	57.9
	1.00	16	42.1	42.1	100.0
	Total	38	100.0	100.0	

ItQ9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	4	10.5	10.5	10.5
	1.00	34	89.5	89.5	100.0
	Total	38	100.0	100.0	

ItQ10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	17	44.7	44.7	44.7
	1.00	21	55.3	55.3	100.0
	Total	38	100.0	100.0	

Frequencies

Statistics

		TOTALpre	TOTALpost
N	Valid	38	38
	Missing	0	0
Mean		5.3947	6.3421
Std. Deviation		2.11225	1.59859

Frequency Table

TOTALpre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	1	2.6	2.6	2.6
	1.00	1	2.6	2.6	5.3
	2.00	1	2.6	2.6	7.9
	3.00	4	10.5	10.5	18.4
	4.00	6	15.8	15.8	34.2
	5.00	3	7.9	7.9	42.1
	6.00	11	28.9	28.9	71.1
	7.00	5	13.2	13.2	84.2
	8.00	4	10.5	10.5	94.7
	9.00	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

TOTALpost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3.00	3	7.9	7.9	7.9
	4.00	1	2.6	2.6	10.5
	5.00	8	21.1	21.1	31.6
	6.00	6	15.8	15.8	47.4
	7.00	10	26.3	26.3	73.7
	8.00	8	21.1	21.1	94.7
	9.00	2	5.3	5.3	100.0
	Total	38	100.0	100.0	

APPENDIX C

(Relates to Chapter 5)

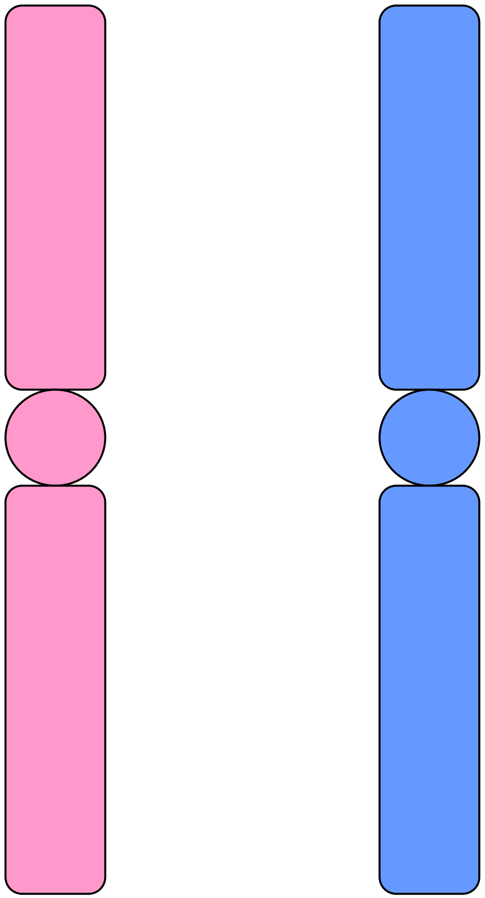
THE CROSSING OVER OF CHROMOSOMES

APPENDIX C.1. a IMAGINE MEIOSIS IN A CELL CONTAINING ONLY <u>TWO</u> CHROMOSOMES . . .
Mother's contribution (PINK CUTOUT) & Father's contribution (BLUE CUTOUT)

PROPHASE 1 Homologous Chromosomes duplicate,

Show the tetrads and the crossing over here

Show the duplication here



Write the traits as seen in the chromosomes:

______________________ ________________________

______________________ ________________________

Result of crossing over – traits as seen in the chromosome now:

________________________ ________________________

________________________ ________________________

Figure C 1

APPENDIX C. 1. b

STUDENTS' WORKSHEET

IMAGINE MEIOSIS IN A CELL CONTAINING ONLY TWO CHROMOSOMES . . .
Mother's contribution (PINK CUTOUT) & Father's contribution (BLUE CUTOUT)
PROPHASE 1 Homologous Chromosomes duplicate,

Show the tetrads and the crossing over here

Show the duplication here

Write the traits as seen in the chromosomes:

Result of crossing over – traits as seen in the chromosome now:

______________________ ______________________ ______________________ ______________________

______________________ ______________________ ______________________ ______________________

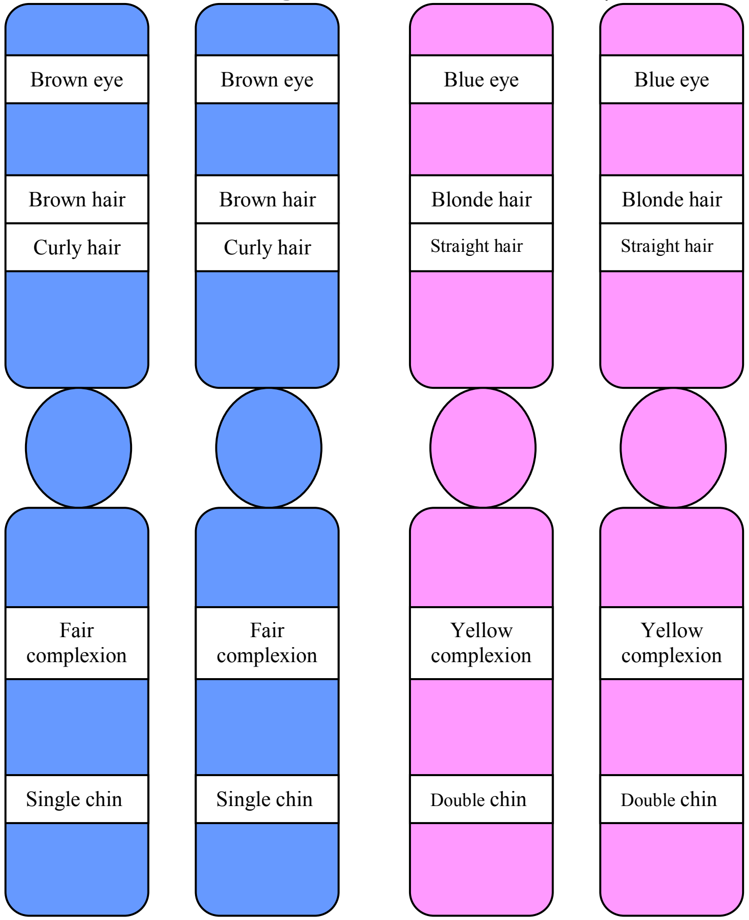
Figure C 2

APPENDIX C. 1. c **An idea of the completed activity of a student's work**

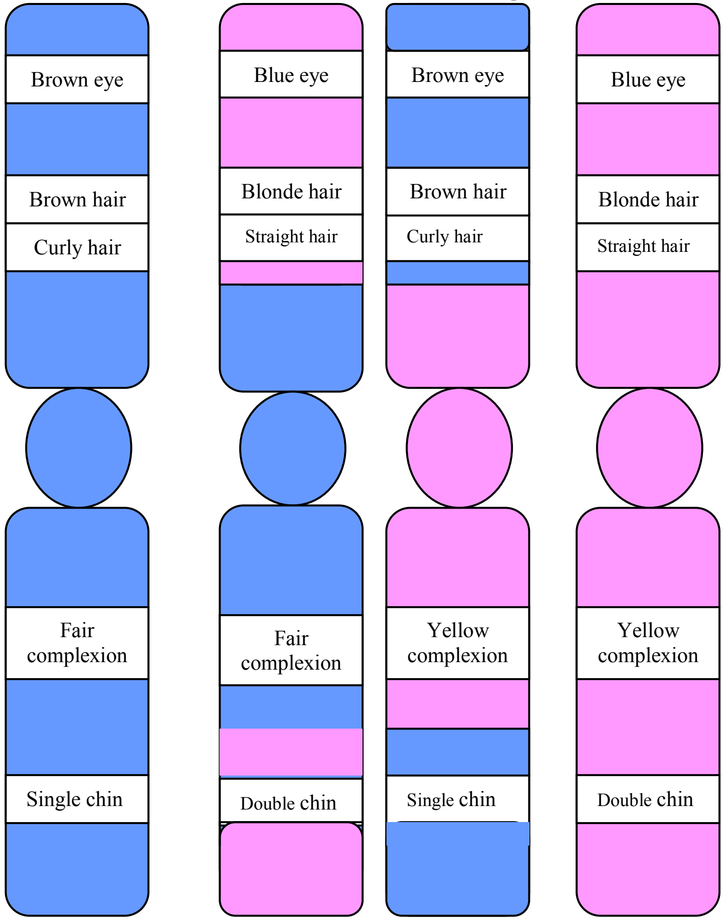
IMAGINE MEIOSIS IN A CELL CONTAINING ONLY TWO CHROMOSOMES . . .

Mother's contribution (PINK CUTOUT) & Father's contribution (BLUE CUTOUT)

MEIOSIS PROPHASE 1 Homologous Chromosomes duplicate,



Show the tetrads and the crossing over here



Write the traits as seen in the chromosomes:

FATHER	MOTHER
Brown eyes, Brown hair Curly hair, Fair complexion Single chin	Blue eyes, Blonde hair Straight hair, Yellow complexion Double chin

Result of crossing over - Write the traits as seen in the chromosome now

REPRODUCTIVE CELLS

Brown eyes, Brown hair, Curly hair, Fair complexion, Single chin	Blue eyes, Blonde hair, Straight hair, Fair complexion, Double chin	Brown eyes, Brown hair, Curly hair, Yellow complexion, Single chin	Blue eyes, Blonde hair, Straight hair, Yellow complexion, Double chin

Figure C 3

APPENDIX C. 2 *The FAR Guide for teaching and learning about the Crossing Over of Chromosomes during Meiosis*

Focus

Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Crossing Over of chromosomes' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a 'cut and paste' paper craft activity.

Action

Likes	Discuss the features of analog and the science concept. Draw similarities between them.	The A4 paper represents the nucleus. The blue cut out and a similar pink cut with traits at different intervals marked by the students themselves represent the paternal and maternal chromosomes containing genes at different loci respectively. Sections cut between the loci, which were mutually exchanged and glued show the homologous chromosomes crossing over and breaking apart after completing the process of crossing over. The resultant cut outs are carefully noted for the changes of genes and the corresponding traits in the recombination, which gives the idea of the consequent genetic variation in the resulting individual. (The details are given below)
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the actual process of protein synthesis largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Similarities mapped out in detail

ANALOG	***ANALOG - FEATURES***	***TARGET***
A 4 Paper	The background for the blue and pink cut outs.	Dividing reproductive cell, where chromosomes are present.
The blue and pink cut outs with labels.	Different chosen traits written by the students at different positions on the cut out. A list showing the traits written at the bottom of each cut out.	The inherited paternal and maternal chromosomes have genes at different loci, which control the traits shown in the resulting individual. The list shows the genes and the corresponding traits in the original chromosome.
Placing another cut out of the same colour beside the existing blue and cut outs.	Two identical cut outs showing the traits.	Homologous chromosomes have duplicated.
Lines drawn on the cut out	The lines the show the different segments and the genes present in those segments of the cut out.	Chiasmata are indicated at positions, where crossing over would occur between the non-sister chromatids.
Cuts are made at these points and the resulting segments are swapped between the adjacent blue and pink cut outs and glued.	Both the cut outs show a combination of two colours glued at the exact intervals.	The chromosomal segments have completed crossing over between non-sister chromatids.
Cut outs showing a combination of blue and pink with a new combination of traits written	The students make a list showing the new combination of traits on all the four cut outs.	After the crossing over, the resulting chromosomes differ from each other and this is the basis for genetic variation in individuals.

Reflection

Conclusions	Was the analog clear and useful or confusing?	The analog seems to be clear and useful. The way the students were engrossed in the activity revealed their interest in the activity. During class discussion, student's preference for the colourful visual was revealed. The interesting comments on the analogy written by the students show that they thoroughly enjoyed the activity and grasped the concept it represented. Their knowledge was revealed when they brought out their own analogies and suggestions to eliminate the only 'dislike' in the analog-target relationship.
Improvements	Refocus as above in light of outcomes.	The analog will be refocused in the light of the above outcomes.

APPENDIX C. 3

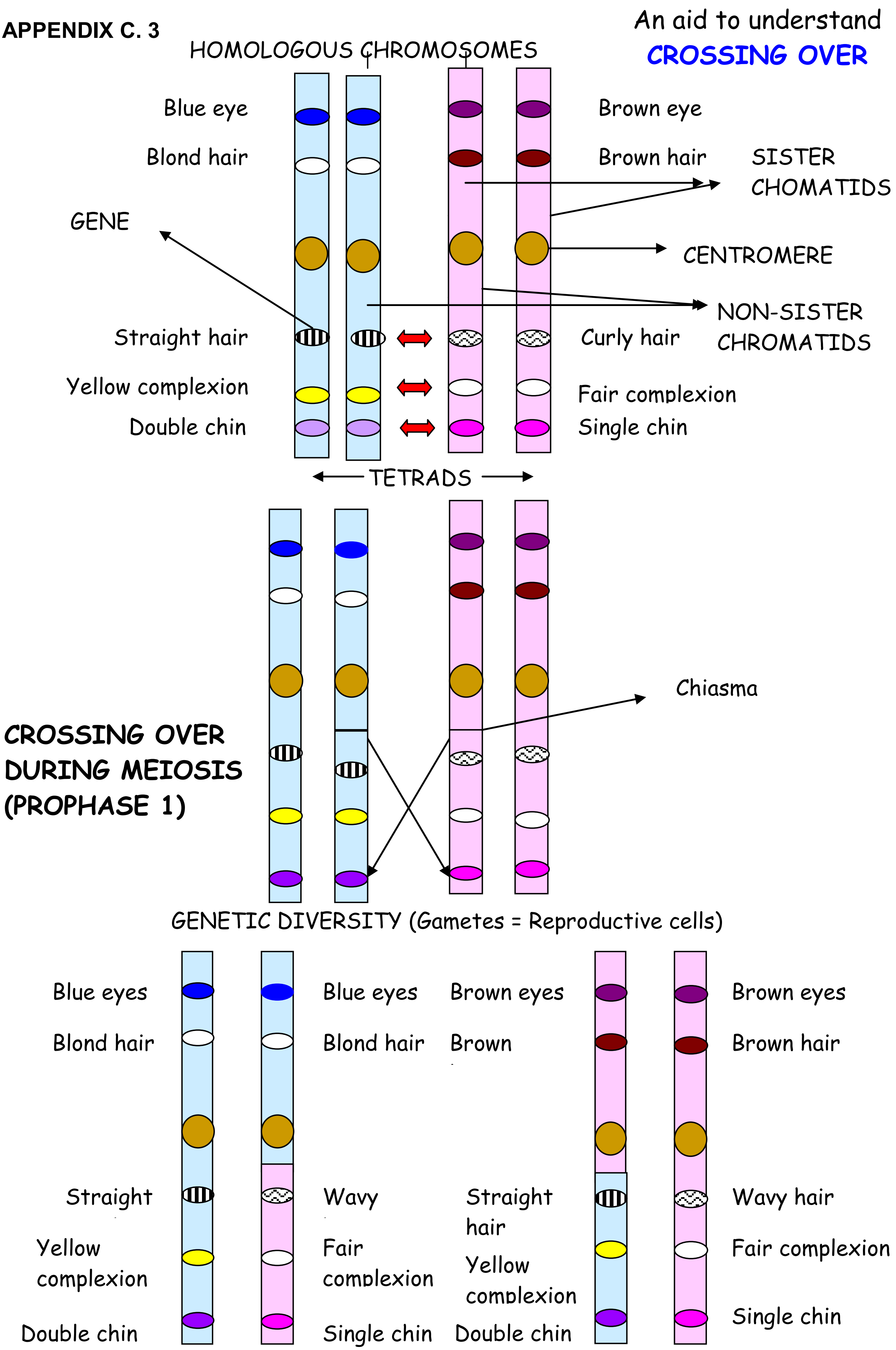


Figure C. 4

APPENDIX C. 4

Two-Tier Diagnostic Instrument on Chromosomal Crossing Over

Procedure and Instrumentation based on the procedure described by Treagust (1986).

What do you know about Chromosomal Crossing Over?

The following pages contain 10 questions about Chromosomal Crossing Over during Meiosis in living organisms. Each question has two parts: A Multiple Choice Response followed by a Multiple Choice Reason. You are asked to make one choice from both the Multiple Choice Response section and one choice from the Multiple Choice Reason section for each question.

If you have another reason for your answer, write in the space provided as well as making the choice letter in the reason box.

Answer all questions on the separate answer sheet

1. Read each question carefully.

2. Take time to calculate and consider your answer.

3. Record your answer in the correct box on the answer sheet.

e.g. Q.5 [2] Reason [ ]

4. Read the set of possible reasons for your answer.

5. Carefully select a reason, which best matches your thinking when you work out the answer.

6. Record your answer in the correct reason box on the Answer sheet.

e.g. Q. 5 [2] Reason [C]

7. If you change your mind about an answer, cross out the old answer and add the new choice.

e.g. Q. 5 [2] Reason [~~C~~] A

8. If you wish to provide your own reason for the question, write your reason on the sheet in the space provided (d).

e.g. Q. 5 [2] Reason [ ] d) ____

____

Don’t forget to record your name and other details on your Answer sheet.

What do you know about the Crossing Over of Chromosomes?

Question 1. Name the cells where crossing over occurs during cell division.
1.Body cells (somatic cells).
2.Reproductive cells (gametes).
3.Brain cells.
4. Any other or your own answer: ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Body cells carry out cell division for growth and at this time, the chromosomes cross over.
b) Reproductive cells divide to produce gametes and crossing over is significant in this process.
c) Brain cells control all the activities of the right and left side of animals and this requires crossing over.
d) **Any other reason for your answer**: ____

Question 2. What is synopsis?
1.Homologous chromosomes pairing along their lengths.
2.Sister chromatids pairing at the centromeres.
3.Homologous chromosomes pairing at chromomeres.
4. Any other or your own answer: ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) The centromeres pair at first and then, the chromatids.
b) The chromomeres are important since they bear the genes.
c) Homologous pairing is the beginning process of meiosis.
d) **Any other reason for your answer**: ____

Question 3. What is the meaning of 'crossing over' in this context?
Your answer:
1) The chromosomes moving across to the opposite poles during mitosis.
2) Certain chromosomes swapping segments.
3) Chromosomal number crossing over to 47 instead of 46.
4) Any other or your own answer: ____

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) The chromosomes move across to the opposite poles after duplication
b) The chromosomes divide and move across to make a total of 47 instead of 46 sometimes.
c) The chromosomes break and rejoin during cell division.
d) Any other reason for your answer: ____

Question 4. During which stage of cell division does crossing over occur?
Your answer:
1.Anaphase of meiosis
2.Telophase 1of mitosis
3.Prophase 1 of meiosis
4 Any other or your own answer: ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) The chromosomes are seen together during the prophase
b) During the anaphase, the chromosomes crossing over to poles.
c) During the telophase, the chromosomes reach the opposite poles.
d) .**Any other reason for your answer:** ____

Question 5. What is 'chiasmata'?
Your answer:
1) The points where twists occur in chromosomes.
2) The points where the chromatids are attached
3) The points where the centromeres are attached
4) Any other or your own answer: ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Chiasmata mean points at which homologous chromosomes intersect.
b) Chiasmata mean points at which chromatids meet the centromeres.
c) Chiasmata mean points at which chromatids hold the genes.
d) Any other reason for your answer: ______________________________

Question 6. What is the purpose of crossing over during cell division?
Your answer:
1) To duplicate chromosomes.
2) To ensure the crossing over of mitotic spindles.
3) To ensure genetic diversity in the offspring.
4) **Any other or your own answer:** ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Chromosomes get duplicated during cell division anyway.
b) The centrosome and mitotic spindles undergo a process of crossing over during cell division.
c) Genetic diversity is essential for the survival of the fittest.
d) **Any other reason for your answer**: ______________________________

Question 8. Which statement best describes the process of 'crossing over'?
1) It takes place between homologous chromosomes and results in increased mutation rate.
2) It takes place between nonhomologous chromosomes and results in increased gene combination.
3) It takes place between homologous chromosomes and results in increased gene combination.
4) **Any other or your own answer:** ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Mutation will occur when homologous genes are involved.
b) Non-homologous crossing over will increase gene combinations.
c) Homologous chromosomes cross over to exchange genetic materials.
d) **Any other reason for your answer**: ______________________________

Question 9. What can we expect, if there is no crossing over?
1) There will not be any variation in the resulting offspring.
2) The genes will mutate.
3) The daughter cells will not have the required number of chromosomes.
4) Any other or your own answer:______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Crossing over alone can keep up the chromosomal number for the species.
b) Genes change if there is no crossing over.
c) Changes in gene combinations will change the traits of the offspring.
d) **Any other reason for your answer**: ______________________________

Question 10. Do you think that crossing over occurs in plant cells?

1) Yes, both plants and animals exhibit a number of similarities and this is one of them.
2) No, the plants are totally different from animals in their structure.
3) No, the plant cells are quite different in carrying out life processes.
4) **Any other or your own answer:** ____

The reason for choosing the above answer:

When I wrote this answer, my thought/s was/were:

a) The plant cells have chlorophyll unlike animals and they photosynthesise.
b) They have to be similar because both are in living organisms.
c) Absence of chromosomes and genes in plants make them different from animals.
d) **Any other reason for your answer** ____

What do you know about crossing over during cell division?

ANSWER SHEET

Name ______________________________ Class: ______________________________

Date: ______________ Male: __________ Female: _________ Age: ___________________

Q. 1 Answer	☐	Q.1 Reason	☐
Q. 2 Answer	☐	Q.2 Reason	☐
Q. 3 Answer	☐	Q.3 Reason	☐
Q. 4 Answer	☐	Q.4 Reason	☐
Q. 5 Answer	☐	Q.5 Reason	☐
Q. 6 Answer	☐	Q.6 Reason	☐
Q. 7 Answer	☐	Q.7 Reason	☐
Q. 8 Answer	☐	Q.8 Reason	☐
Q. 9 Answer	☐	Q.9 Reason	☐
Q. 10 Answer	☐	Q.10 Reason	☐

What do you know about Crossing Over?

ANSWER SHEET

Name ________________________________ Class: ________________________________

Date: _______________ Male: ___________ Female: __________ Age: __________________

Q. 1 Answer	2	Q.1 Reason	b
Q. 2 Answer	1	Q.2 Reason	c
Q. 3 Answer	2	Q.3 Reason	c
Q. 4 Answer	3	Q.4 Reason	a
Q. 5 Answer	1	Q.5 Reason	a
Q. 6 Answer	3	Q.6 Reason	c
Q. 8 Answer	3	Q.8 Reason	c
Q. 9 Answer	1	Q.9 Reason	c
Q. 10 Answer	1	Q.10 Reason	b

APPENDIX C. 5

Table C. 1 Analysis of Individual Responses

	Concept - Chromosomal Crossing Over	Average %		
		Pretest	posttest	Increase/ Decrease
Q.No.1	**Name the cells where crossing over occurs during cell division.**			
Correct Answer	**2. Reproductive cells (gametes).**	52.17	91.30	39.13
Misconception	1. Body cells (somatic cells).	30.43	4.35	-26.08
Misconception	3. Brain cells.	13.04	4.35	-8.69
Misconception	Students' own	4.35	0	-4.35
Correct Reason	**b) Reproductive cells divide to produce gametes and crossing over is significant in this process.**	60.87	86.96	26.09
Misconception	a) Body cells carry out cell division for growth and at this time, the chromosomes cross over.	26.09	8.70	-17.39
Misconception	c) Brain cells control all the activities of the right and left side of animals and this requires crossing over.	13.04	4	-8.69
Q.No.2	**What is synopsis?**			
Correct Answer	**1. Homologous chromosomes pairing along their lengths.**	13.04	43.48	30.44
Alternate conception	2. Sister chromatids pairing at the centromeres.	43.48	21.74	-21.74
Alternate conception	3.Homologous chromosomes pairing at chromomeres.	43.48	34.78	-8.70
Correct Reason	**c) Homologous pairing is the beginning process of meiosis.**	47.83	65.22	17.39
Alternate conception	a) The centromeres pair at first and then, the chromatids.	21.74	30.43	8.69
Misconception	b) The chromomeres are important since they bear the genes.	26.09	4.35	-21.74
Misconception	Students' own			
Q.No.3	**What is the meaning of 'crossing over' in this context?**			
Correct Answer	**2) Certain chromosomes swapping segments.**	47.83	91.30	43.47
Misconception	1) The chromosomes moving across to the opposite poles during mitosis.	47.83	8.70	-39.13
Misconception	3) Chromosomal number crossing over to 47 instead of 46.	4.35	0	-4.35
Misconception	Students' own			
Correct Reason	**c) The chromosomes break and rejoin during cell division.**	47.83	47.83	0
Alternate conception	a) The chromosomes move across to the opposite poles after duplication	43.48	39.13	-4.35
Misconception	b) The chromosomes divide and move across to make a total of 47 instead of 46 sometimes.	4.35	8.70	4.35

Q.1. Name the cells where crossing over occurs during cell division.

Correct Answer: 2. Reproductive cells (gametes).

There was an increase of 39% after the presentation of the analogy, which indicates that the analogy was beneficial to the students' understanding of the concept. The posttest score was 91% for this correct answer.

1. Body cells (somatic cells).

3. Brain cells.

The above two misconceptions were held by 4% of the students respectively.

Correct reason: b) Reproductive cells divide to produce gametes and crossing over is significant in this process.

This conception was held by 87% of the students, who became aware that this process is significant in the production of gametes to ensure genetic diversity.

a) Body cells carry out cell division for growth and at this time, the chromosomes cross over.

c) Brain cells control all the activities of the right and left side of animals and this requires crossing over.

The above misconceptions were reduced by 17% and 9% respectively and existed as misconception in 9% and 4% of the cohort respectively, which were clarified later.

Q.2. **What is synopsis?**

Correct answer: 1. Homologous chromosomes pairing along their lengths.

There was an increase of 30% in the posttest average from the pretest average and 43% of the students held this concept, indicating that the analogy presented was effective.

2. Sister chromatids pairing at the centromeres.

Though there was a decrease of 22% in the posttest average, this alternate conception was still held by 22% of the students. This needed clarification and was taken up during the posttest review and the students were given assistance to understand this concept.

3. *Homologous chromosomes pairing at chromomeres.*

This alternate conception was held by 35% of the students and was explained again for the students' better understanding. There was a decrease of 9% this alternate conception in the posttest average.

Correct reason: c) Homologous pairing is the beginning process of meiosis.

This concept was held by 65% of the students and showed an increase of 17% from the pre to posttest average after the presentation of the analogy.

a) *The centromeres pair at first and then, the chromatids.*

This alternate conception was held by 30% of the students and showed an increase of 9% after the presentation of the analogy. The posttest review revealed that they were still getting familiar with the new scientific terms learnt when the test was administered and were unable to distinguish between centromeres and chromatids.

b) *The chromomeres are important since they bear the genes*

This is a misconception held by 4% of the cohort.

Q.3. What is the meaning of 'crossing over' in this context?

Correct answer: 2) Certain chromosomes swapping segments.

This concept was held by 91%, which resulted from an increase of 43% from the pretest average after the presentation of the analogy.

1) The chromosomes moving across to the opposite poles during mitosis.

3) Chromosomal number crossing over to 47 instead of 46.

The above misconception (1) was held by 9% of the cohort as shown by the pretest average, but none chose the above reason (3) as the correct answer in the posttest.

Correct reason: c) The chromosomes break and rejoin during cell division.

The pretest and posttest scores remained unchanged and stayed at 48%, indicating that the analogy didn't help to change their misconceptions or alternate conceptions unfortunately.

a) The chromosomes move across to the opposite poles after duplication.

This alternative conception was held by 39% of the students. The students were not sure whether the movement of the chromosomes to the opposite poles or the movement of chromosomal bits between the non-sister chromosome is known as 'crossing over'. This was taken up for discussion during the posttest review and the meaning was clarified and reinforced for understanding.

b) The chromosomes divide and move across to make a total of 47 instead of 46 sometimes.

This misconception was held by 9% of the student which was clarified during the posttest review.

Table C. 1 Continued. . .	Concept - Chromosomal Crossing Over	Average %		
		Pretest	posttest	Increase/ Decrease
Q.No.4	**During which stage of cell division does crossing over occur?**			
Correct Answer	**3. Prophase 1 of meiosis**	30.43	78.26	47.83
Alternate conception	1. Anaphase of meiosis	39.13	13.04	-26.09
Misconception	2. Telophase 1of mitosis	30.43	8.70	-21.73
Correct Reason	**a) The chromosomes are seen together during the prophase.**	43.48	73.91	30.43
Misconception	b) During the anaphase, the chromosomes crossing over to poles.	43.48	8.70	-34.78
Alternate conception	c) During the telophase, the chromosomes reach the opposite poles.	13.04	13.04	0.00
Misconception	Students' own	0	4.35	4.35
Q.No.5	**What is 'chiasmata'?**			
Correct Answer	**1) The points where twists occur in chromosomes.**	43.48	69.57	26.09
Alternate conception	2) The points where the chromatids are attached	47.83	26.09	-21.74
Misconception	3) The points where the centromeres are attached	8.70	4.35	-4.35
Correct Reason	**a) Chiasmata mean points at which homologous chromosomes intersect.**	56.52	47.83	-8.69
Alternate conception	b) Chiasmata mean points at which chromatids meet the centromeres.	21.74	17.39	-4.35
Alternate conception	c) Chiasmata mean points at which chromatids hold the genes.	17.39	26.69	9.30
Misconception	Students' own	4.35	4.35	0.00
Q.No.6	**What is the purpose of crossing over during cell division?**			
Correct Answer	3. To ensure genetic diversity in the offspring.	0	69.57	69.57
Alternate conception	1. To duplicate chromosomes.	47.83	17.39	-30.44
Alternate conception	2. To ensure the crossing over of mitotic spindles.	52.17	13.04	-39.13
Correct Reason	c) Genetic diversity is essential for the survival of the fittest.	34.78	47.83	13.05
Alternate conception	a) Chromosomes get duplicated during cell division anyway.	43.48	30.43	-13.05
Alternate conception	b) The centrosome and mitotic spindles undergo a process of crossing over during cell division.	21.74	17.39	-4.35
Misconception	Students' own	4.35	4.35	0

Q.4. During which stage of cell division does crossing over occur?

Correct answer: 3.Prophase 1 of meiosis.

The posttest average showed an increase of 48% after the presentation of the analogy and 78% of the students chose this correct answer.

1. Anaphase of meiosis

The posttest average showed a decrease of 26% and only 13% held this misconception, which was taken up for discussion and clarified later..

2. Telophase of meiosis

This misconception was still held by 9% of the students, though the average decreased by 22%. Posttest review clarified this for the students.

Correct reason: a) The chromosomes are seen together during the prophase.

The posttest average showed an increase of 30% after the presentation of the analogy and this conception was held by 74% of the students.

b) During the anaphase, the chromosomes crossing over to poles.

This misconception was held by 9% of the students.

c) During the telophase, the chromosomes reach the opposite poles.

The movement of chromosomes to the poles was considered to be 'crossing over' by 13% of the students and this was clarified during the posttest review.

Q.5. What is 'chiasmata'?

Correct answer: 1) The points where twists occur in chromosomes.

This answer was chosen by 70% of the students and there was an increase of 26% from the pretest after the presentation of the analogy.

2) The points where the chromatids are attached.

This alternate conception was held by 26% of the students in the posttest and this is 22% less than the pretest average. This was discussed during the posttest review and the students' doubts were clarified.

3) The points where the centromeres are attached.

This misconception was held by only 4%.

Correct reason: a) Chiasmata mean points at which homologous chromosomes intersect.

Unfortunately 9% of the students developed this alternate conception after the presentation of the analogy and the posttest average was less than the pretest average. This correct answer was chosen by 48% of the students.

b) Chiasmata mean points at which chromatids meet the centromeres.

Overall, the students found this concept of crossing over very difficult to understand. It was observed that the students needed more effort to comprehend and retain the technical terms associated with this concept in memory. 17% held this alternate conception, which showed a marginal decrease of 4% from the pretest and a detailed posttest review clarified these points for them.

c) Chiasmata mean points at which chromatids hold the genes.

Confusion between foci and chiasmata could have made 9% of the students develop this alternate conception after the presentation of the analogy. 27% held this alternate conception and this was taken up and explained for better understanding.

Q.6. What is the purpose of crossing over during cell division?

Correct answer: 3. To ensure genetic diversity in the offspring.

None chose the correct answer in the pretest, but 70% of the students chose this answer in the posttest showing that the analogy did play a significant role in understanding.

1. To duplicate chromosomes.

This alternate conception was held by 17% of the students and a significant decrease of 30% from the pretest average resulted in this average.

2. To ensure the crossing over of mitotic spindles.

This alternate conception was held by13% of the students and this is 39% less than the pretest average. These two concepts were clearly explained during the posttest review.

Correct reason: c) Genetic diversity is essential for the survival of the fittest.

This correct answer was chosen by 48% of the cohort, which is 13% more than the pretest average, which shows that the analogy did benefit them to a certain extent.

a) Chromosomes get duplicated during cell division anyway.

Chromosomes get duplicated during cell division anyway with or without a purpose. This alternate conception was held by a significant number of students and the posttest average was 30%, which was 13% less than the posttest average. They failed to see the reason for the chromosomes dividing and crossing over in meiosis as a significant event. This explained to them during the posttest review.

b) The centrosome and mitotic spindles undergo a process of crossing over during cell division.

This alternate conception was still held by 17% of the students, though this was reduced by 4% after the presentation of the analogy. This was discussed and clarified.

Table C. 1 Continued. . .	**Concept - Chromosomal Crossing Over**	**Average %**		
		Pretest	**posttest**	**Increase/ Decrease**
Question. 8	**Which statement best describes the process of 'crossing over'?**			
Correct Answer	3.It takes place between homologous chromosomes and results in increased gene combination.	47.83	60.87	13.04
Misconception	1. It takes place between homologous chromosomes and results in increased mutation rate.	21.74	0	-21.74
Alternate conception	2. It takes place between non-homologous chromosomes and results in increased gene combination.	30.43	39.13	8.70
Correct Reason	b) Non-homologous crossing over will increase gene combinations.	30.43	21.74	-8.69
Misconception	a) Mutation will occur when homologous genes are involved.	21.74	8.70	-13.04
Alternate conception	c) Homologous chromosomes cross over to exchange genetic materials.	47.83	65.22	17.39
Misconception	Students' own	0	4.35	4.35
Question. 9	**What can we expect, if there is no crossing over?**			
Correct Answer	1) There will not be any variation in the resulting offspring.	56.52	78.26	21.74
Alternate conception	2) The genes will mutate.	13.04	13.04	0.00
Misconception	3) The daughter cells will not have the required number of chromosomes.	30.43	8.70	-21.73
Correct Reason	c) Changes in gene combinations will change the traits of the offspring.	26.09	82.61	56.52
Misconception	a) Crossing over alone can keep up the chromosomal number for the species.	56.52	8.70	-47.82
Misconception	b) Genes change if there is no crossing over.	13.04	4.35	-8.69
Misconception	Students' own	4.35	4.35	0
Question. 10	**Do you think that crossing over occurs in plant cells?**			
Correct Answer	1) Yes, both plants and animals exhibit a number of similarities and this is one of them.	43.48	69.57	26.09
Alternate conception	2) No, the plants are totally different from animals in their structure.	17.39	13.04	-4.35
Alternate conception	3) No, the plant cells are quite different in carrying out life processes.	39.13	17.39	-21.74
Correct Reason	b) They have to be similar because both are in living organisms.	26.09	47.83	21.74
Alternate conception	a) The plant cells have chlorophyll unlike animals and they photosynthesise.	39.13	26.09	-13.04
Alternate conception	c) Absence of chromosomes and genes in plants make them different from animals.	34.78	21.74	-13.04
Misconception	Students' own	0	4.35	4.35

Q. 8. Which statement best describes the process of 'crossing over'?

Correct answer: 3.It takes place between homologous chromosomes and results in increased gene combination.

This correct conception was held by 61% of the students after the presentation of the analogy, an increase of 13% from the pretest average, indicating a positive effect of the analogy on student understanding.

1. It takes place between homologous chromosomes and results in increased mutation rate.

Though 22% of the students chose this answer in the pretest, none of the students chose this answer in the posttest. The only explanation could be that the analogy helped them to get the concept that if crossing over takes place between the homologous chromosomes, it will not cause any mutation in the genes or chromosomes.

2. It takes place between non-homologous chromosomes and results in increased gene combination.

This alternate conception was held by 39% of the students unfortunately, and resulted due to the mix up of the technical terms, 'non-homologous' and 'homologous'. The students were not able to assign the correct terminology to the corresponding structure. This needed an effective review of the process and was done during the posttest review.

Correct reason: c) Homologous chromosomes cross over to exchange genetic materials.

This correct conception was held by 65% of the students, which is an increase of 17% from the pretest average, which suggests that the significance of the crossing over process had been comprehended to a large extent.

a) Mutation will occur when homologous genes are involved.

This misconception was reduced by 13% and was held by 9% of the students and was clarified during the posttest review.

b) Non-homologous crossing over will increase gene combinations.

There was an decrease of 22% from the pretest average for this reason and the posttest average was 22%. The uncertainty between the terms, 'non-homologous' and 'homologous' was removed during the posttest review and it was ensured that the students understood the underlying principle of crossing over. Similar occurrences made me include the teaching module of introducing the Greek and Latin origin of the terms every year. This module was recommended to the Head of the Department of the school, where I worked for a short time and he informed me recently that they have included this program on a regular basis for their science students from Year 8.

Q.9. What can we expect, if there is no crossing over?

Correct answer: 1) There will not be any variation in the resulting offspring.

This answer was chosen by 78% of the students and showed an increase of 22% from the pretest average showing that the analogy helped in better understanding.

2) The genes will mutate.

The pretest and posttest average remained the same and was at 13%. This alternate conception was taken up for discussion during the posttest review and the students' doubts were clarified.

3) The daughter cells will not have the required number of chromosomes.

The posttest average showed that this misconception was held by 9% of the students.

Correct reason: c) Changes in gene combinations will change the traits of the offspring.

This reason was chosen by 83% in the posttest, an increase of 57% from the pretest. The analogy aimed at emphasizing this particular significance of the process of crossing over as a means of bringing about variations in the resulting offspring for better chances of survival. This purpose was largely achieved by the presentation of the analogy using the FAR Guide.

a) Crossing over alone can keep up the chromosomal number for the species.

The above misconception was reduced by 48% after the presentation of the analogy and was held only by 9% of the students.

b) Genes change if there is no crossing over.

The above two misconceptions was held by 4% of the students and the posttest score showed that this misconception was reduced by 9% after the presentation of the analogy.

Q.10.Do you think that crossing over occurs in plant cells?

Correct answer: 1) Yes, both plants and animals exhibit a number of similarities and this is one of them.

This answer was chosen by 70% of the students after the presentation of the analogy, which is an increase of 26% from the pretest, indicating the benefit of teaching with analogy.

2) No, the plants are totally different from animals in their structure.

This alternate conception was held by 13% of the students though there was a decrease of 4% from the pretest. This was taken up for discussion and clarified during the posttest review.

3) No, the plant cells are quite different in carrying out life processes.

This alternate conception was held by 17% of the students, which is 22% less than the pretest average, indicating that the students became aware that the plants and animals share the same characteristics. This was further clarified during the posttest review to make the students understand that plants and animals are a lot similar at basic levels.

Correct reason: b) They have to be similar because both are in living organisms.

The posttest average showed an increase of 22% from the pretest average and 48% of the students held this view after the presentation of the analogy.

a) The plant cells have chlorophyll unlike animals and they photosynthesize.

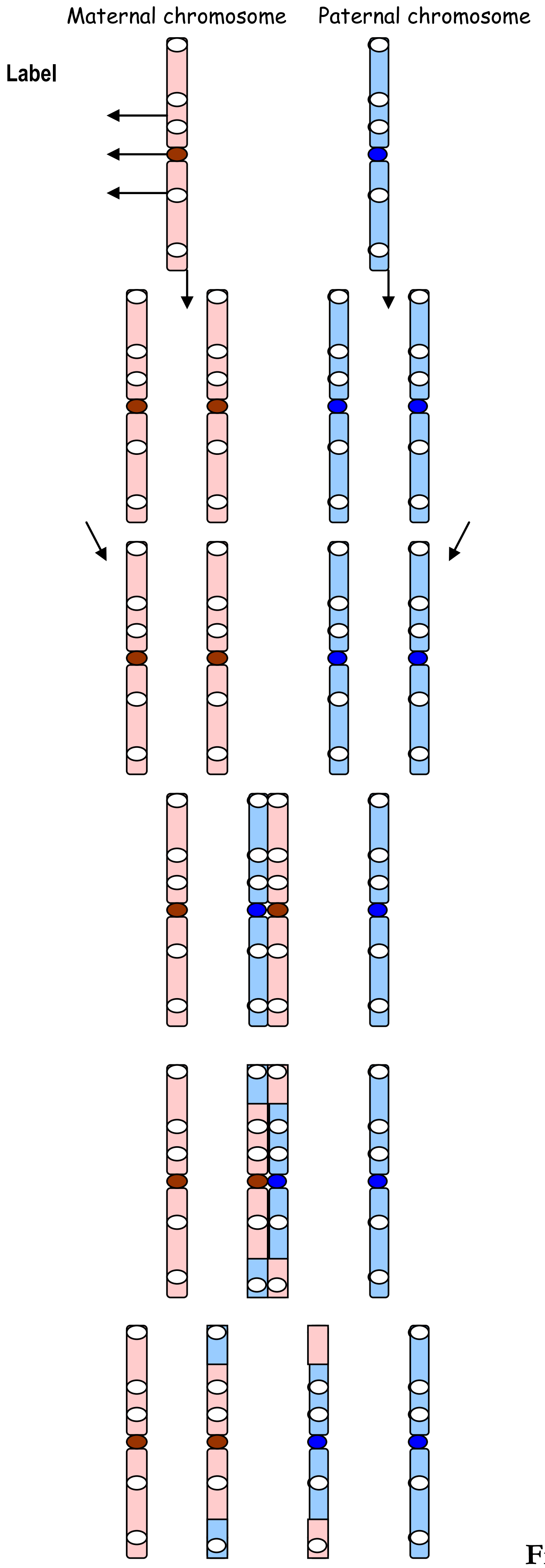
This alternate conception has no correlation with the question; yet 26% of the students chose this reason to support the answer. The posttest review clarified these points.

c) Absence of chromosomes and genes in plants make them different from animals.

This alternate conception was reduced by 13% after the presentation of the analogy and was still held by 22% of the students and needed further clarification, which was carried out satisfactorily during the posttest review.

APPENDIX C. 6

A Worksheet on Crossing Over



Name the cells where these are present:

Name the stage:

Name the chromosomes:

Name the process:

Name the chromatids (Pink & Pink):

Name the chromatids (Pink & Blue):

Name the chromosomes (together):

Name the process:

Name the process **completed**:

Describe the result in two words:

G _ _ _ _ _ _ D _ _ _ _ _ _ _ _

Figure C. 5

APPENDIX C. 7

Students' Worksheet

Analog - Target Mapping for Chromosomal Crossing Over

Similarities between the analog and the target

ANALOG in your activity	TARGET
eg. A4 paper	Reproductive cell
	Maternal chromosome
	Paternal chromosome
	Homologous chromosomes
	Stage when maternal and paternal chromosomes double up Prophase1 in Meiosis
	Doubled up chromosomes
	Tetrad
	Genes and the corresponding traits
	Sister chromatids
	Non-sister chromatids
	Synapsis
	Chiasmata
	Crossing over
	Genetic recombination in the chromosome

Where does this analogy break down? i.e. where is this analogy NOT like the chromosomal crossing over in a real cell?

APPENDIX C. 8

An Analogy activity

(Analogy is a real life example, (in this case, the activity), which generally resembles the complex scientific concept to a large extent. An analogy is given to you to help you to understand a difficult concept, which you are unable to visualise with your eyes).

Chromosomal Crossing over during meiotic cell division

You are given a **familiar example** as an activity to help you to understand the concept of chromosomal crossing over during meiosis. The given example is known as an **analog** (paper craft) and the **comparison or the association that you relate to this analog** is known as the **target** (crossing over of chromosomes).

1. Did this activity help you to understand the principles involved in chromosomal crossing over better than before?

____

____

2. Explain giving reasons supporting your answer.

____

____

____

____

3. Is this analogy–activity **exactly like** the chromosomal crossing over and when is it **not like** the chromosomal crossing over (known as the 'breaking down' of the given analogy)? Explain your answer.

____

____

____

____

4. Can you think of **any other analogy (real life example) of your own**, which might help you to understand the chromosomal crossing over better? Give it in the space below:

____

____

____

____

You may use overleaf, if you need more space

APPENDIX C. 9 a, b, c

Chromosomal Crossing Over

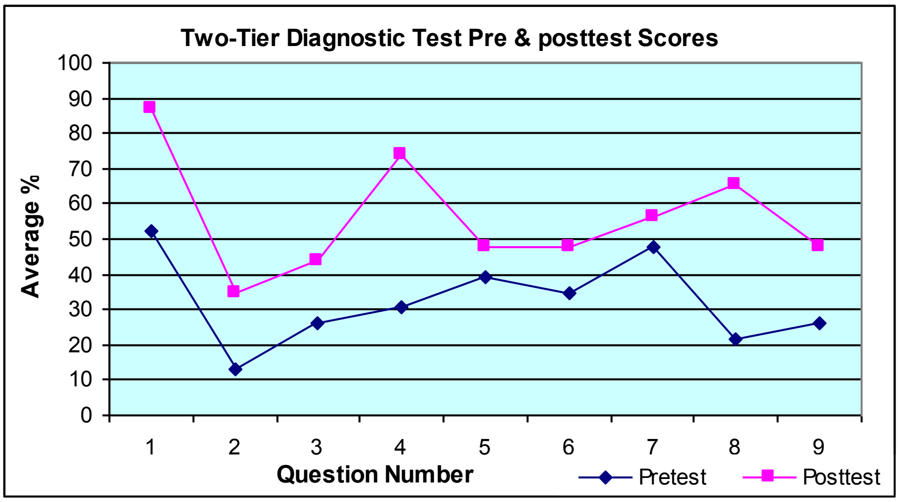


Figure C 6 a. Graph: Class Test Results

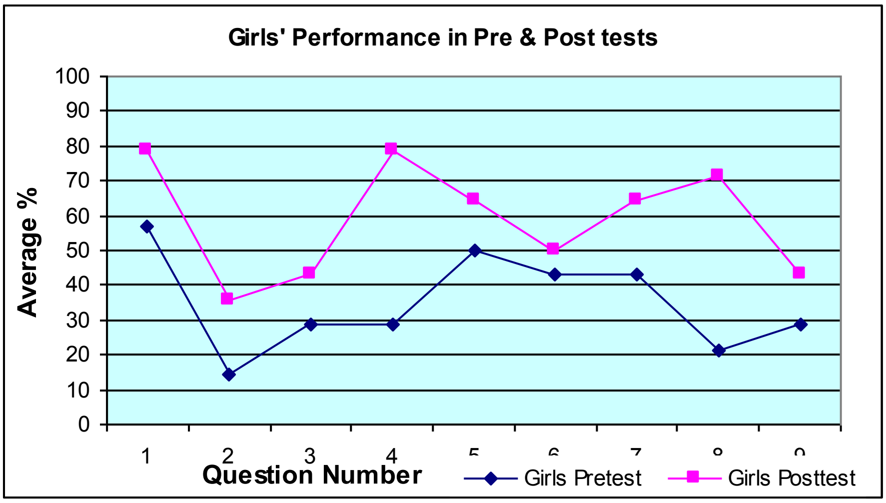


Figure C 6 b. Graph: Girls' performance

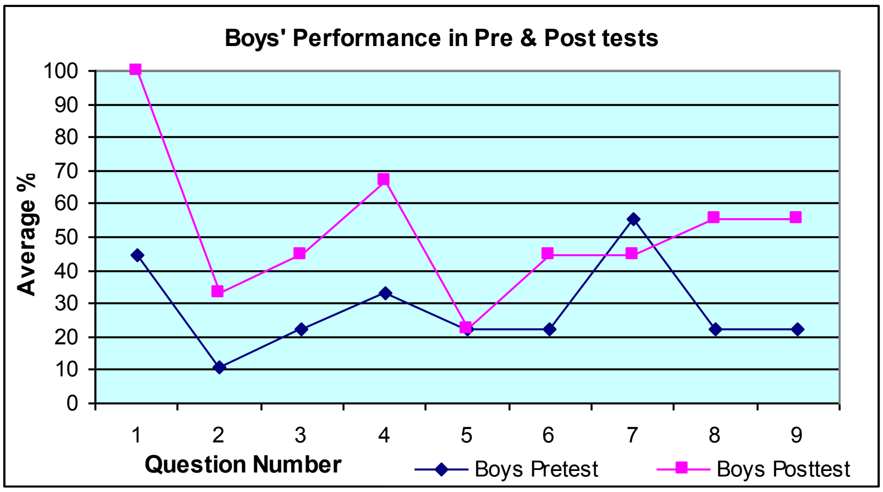


Figure C 6 c. Graph: Boys' performance

APPENDIX C 9 d, e

Gender differences

Chromosomal Crossing over

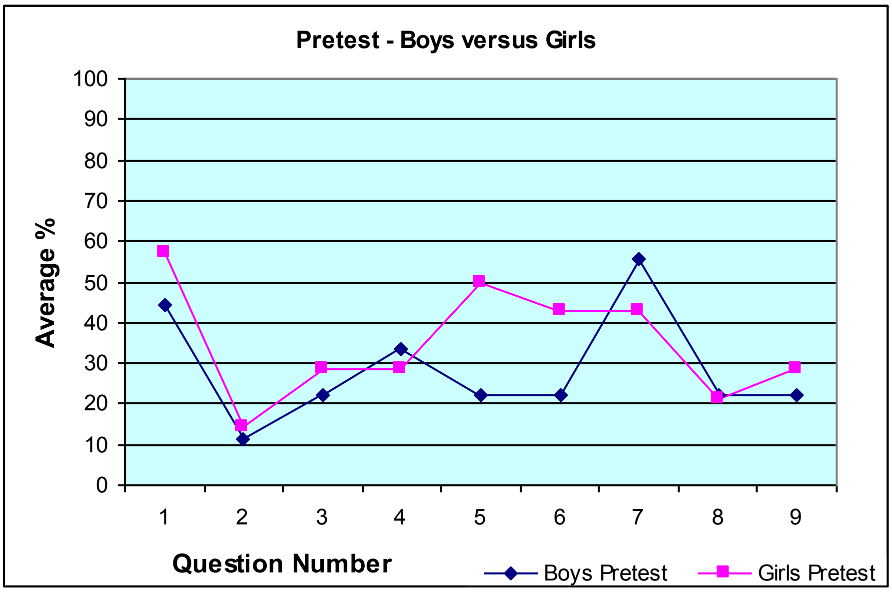


Figure C 6 d. Graph: Pretest - Boys versus Girls

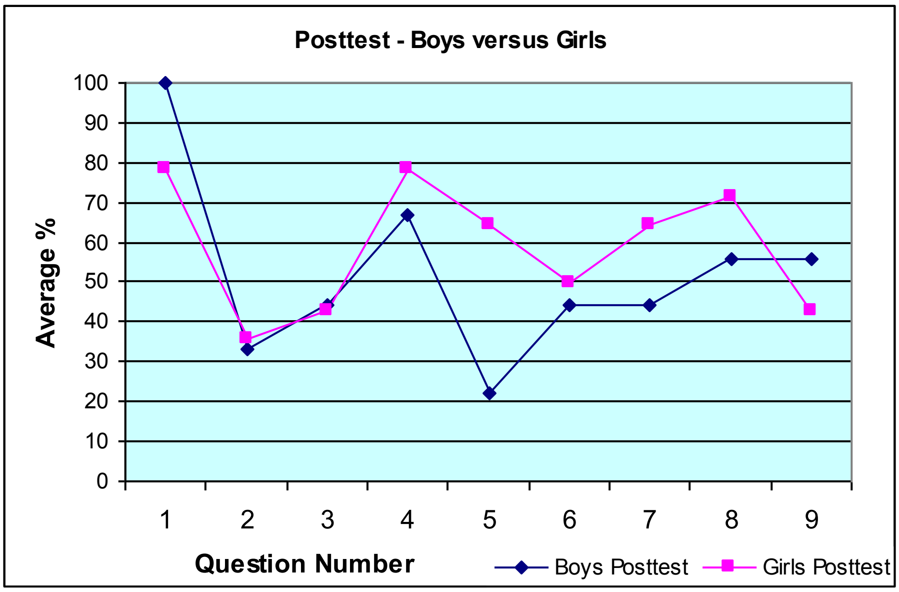
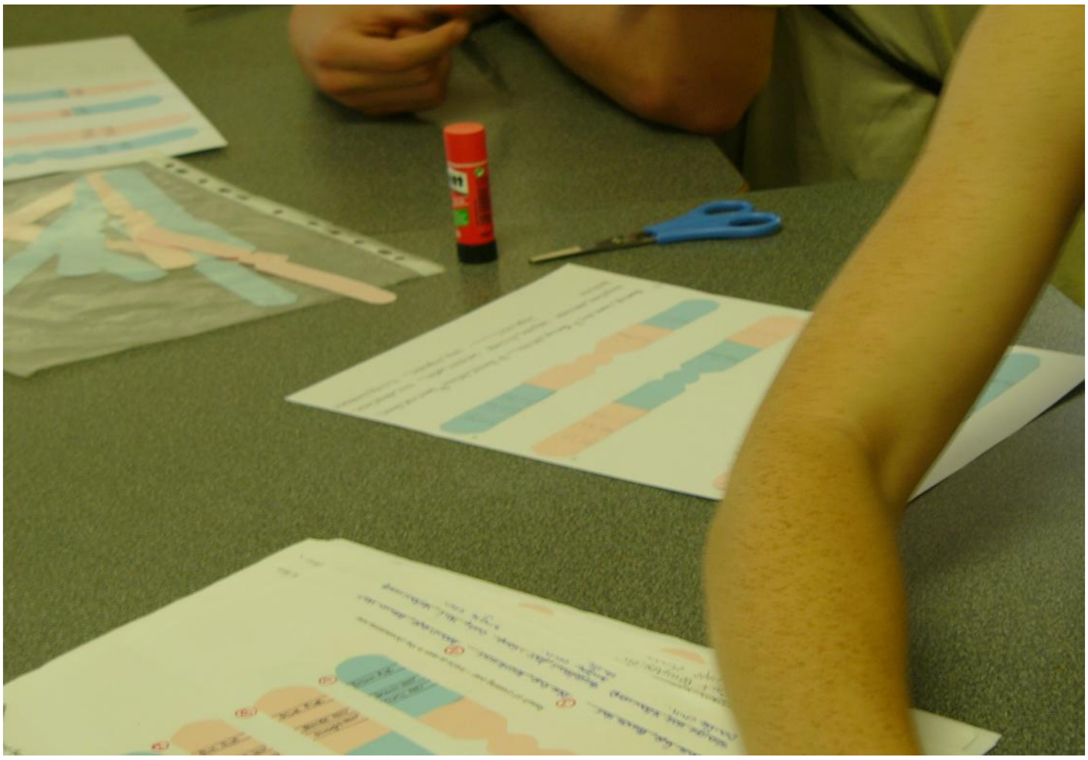


Figure C 6 e. Graph: Posttest - Boys versus Girls

APPENDIX C.10

Chromosomal Crossing over

Cut and Paste



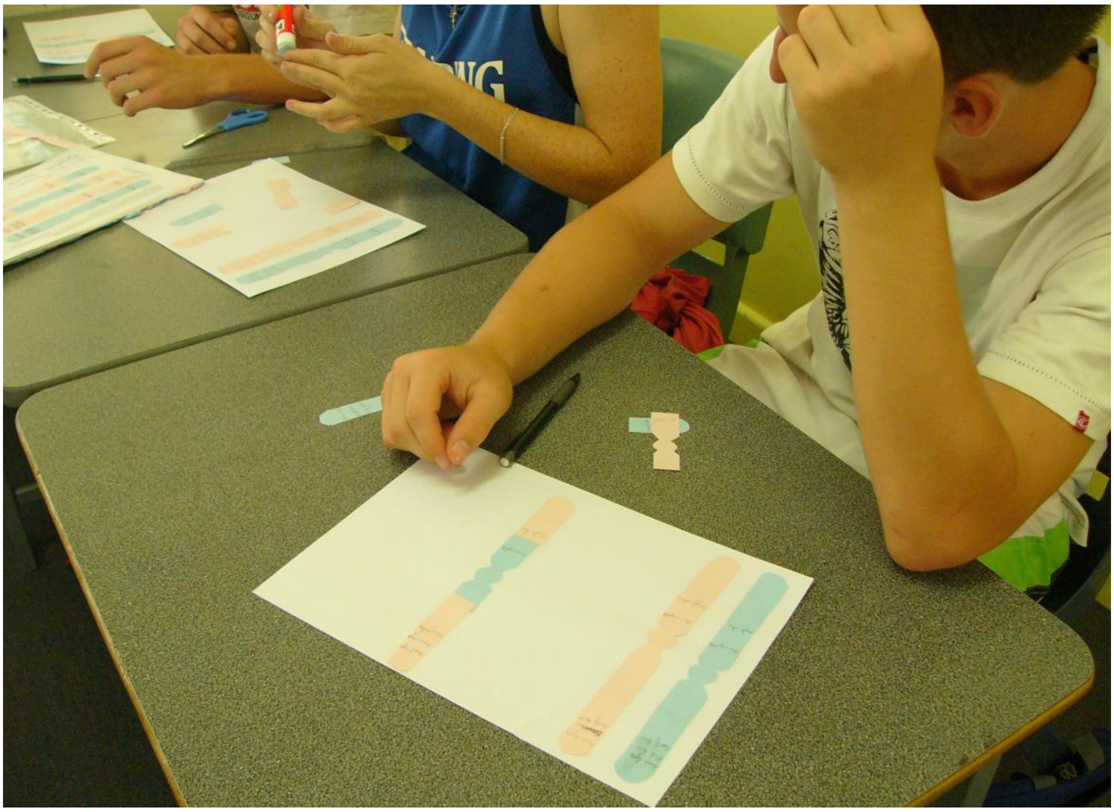
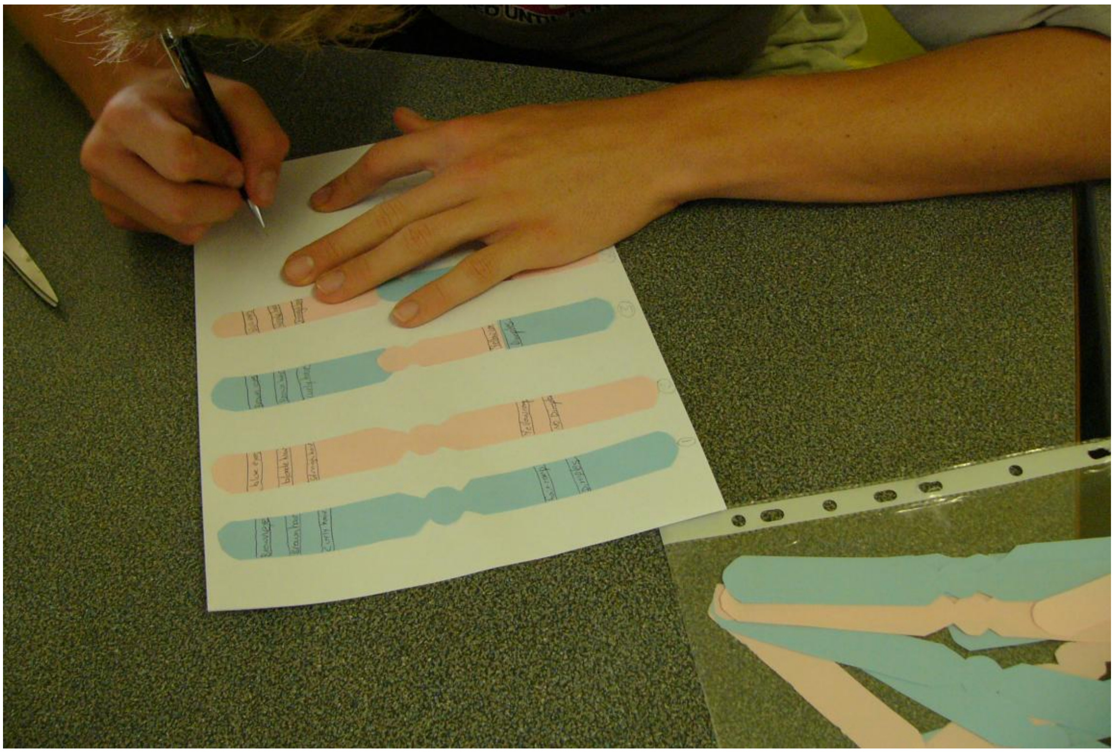


Figure C 7 Adding combinations. . .



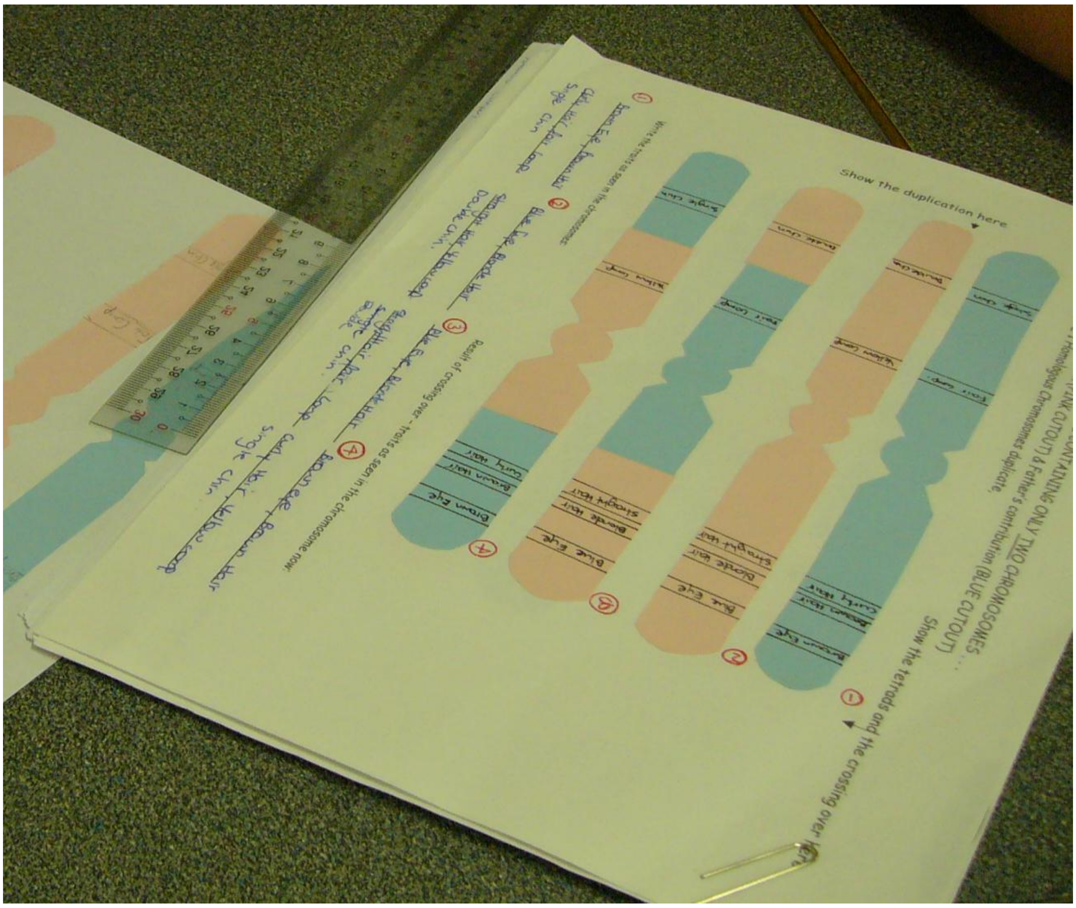


Figure C 7 **Genetic Diversity**

APPENDIX C. 11

FREQUENCIES

Frequency Table: Pretest-posttest combined sample

Pre 1

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	11	47.8	47.8	47.8
1	12	52.2	52.2	100.0
Total	23	100.0	100.0	

Pre 2

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	20	87.0	87.0	87.0
1	3	13.0	13.0	100.0
Total	23	100.0	100.0	

Pre 3

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	17	73.9	73.9	73.9
1	6	26.1	26.1	100.0
Total	23	100.0	100.0	

Pre 4

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	16	69.6	69.6	69.6
1	7	30.4	30.4	100.0
Total	23	100.0	100.0	

Pre 5

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	14	60.9	60.9	60.9
1	9	39.1	39.1	100.0
Total	23	100.0	100.0	

Pre 6

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid 0	15	65.2	65.2	65.2
1	8	34.8	34.8	100.0
Total	23	100.0	100.0	

Pre 8

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	12	52.2	52.2	52.2
	1	11	47.8	47.8	100.0
	Total	23	100.0	100.0	

Pre 9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	18	78.3	78.3	78.3
	1	5	21.7	21.7	100.0
	Total	23	100.0	100.0	

Pre 10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	17	73.9	73.9	73.9
	1	6	26.1	26.1	100.0
	Total	23	100.0	100.0	

Post 1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	3	13.0	13.0	13.0
	1	20	87.0	87.0	100.0
	Total	23	100.0	100.0	

Post 2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	15	65.2	65.2	65.2
	1	8	34.8	34.8	100.0
	Total	23	100.0	100.0	

Post 3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	13	56.5	56.5	56.5
	1	10	43.5	43.5	100.0
	Total	23	100.0	100.0	

Post 4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	6	26.1	26.1	26.1
	1	17	73.9	73.9	100.0
	Total	23	100.0	100.0	

Post 5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	12	52.2	52.2	52.2
	1	11	47.8	47.8	100.0
	Total	23	100.0	100.0	

Post 6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	12	52.2	52.2	52.2
	1	11	47.8	47.8	100.0
	Total	23	100.0	100.0	

Post 8

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	43.5	43.5	43.5
	1	13	56.5	56.5	100.0
	Total	23	100.0	100.0	

Post 9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	8	34.8	34.8	34.8
	1	15	65.2	65.2	100.0
	Total	23	100.0	100.0	

Post 10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	12	52.2	52.2	52.2
	1	11	47.8	47.8	100.0
	Total	23	100.0	100.0	

TOTAL Pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	4.3	4.3	4.3
	1	5	21.7	21.7	26.1
	2	3	13.0	13.0	39.1
	3	8	34.8	34.8	73.9
	4	1	4.3	4.3	78.3
	5	3	13.0	13.0	91.3
	6	1	4.3	4.3	95.7
	7	1	4.3	4.3	100.0
	Total	23	100.0	100.0	

TOTAL Post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	2	8.7	8.7	8.7
	2	3	13.0	13.0	21.7
	3	1	4.3	4.3	26.1
	4	2	8.7	8.7	34.8
	5	5	21.7	21.7	56.5
	6	3	13.0	13.0	69.6
	7	3	13.0	13.0	82.6
	8	3	13.0	13.0	95.7
	9	1	4.3	4.3	100.0
	Total	23	100.0	100.0	

		Item1 pre	Item2 pre	Item3 pre	Item4 pre	Item5 Pre	Item6 pre	Item8 pre	Item9 pre	Item10 pre
N	Valid	23	23	23	23	23	23	23	23	23
	Missing	0	0	0	0	0	0	0	0	0

		Item1 post	Item2 post	Item3 post	Item4 post	Item5 post	Item6 post	Item8 post	Item9 post	Item10 post
N	Valid	23	23	23	23	23	23	23	23	23
	Missing	0	0	0	0	0	0	0	0	0

APPENDIX D

(Relates to Chapter 6)

PROTEIN SYNTHESIS

APPENDIX D. 1 a

PROTEIN SYNTHESIS & A TOY ASSEMBLY – AN ANALOGY

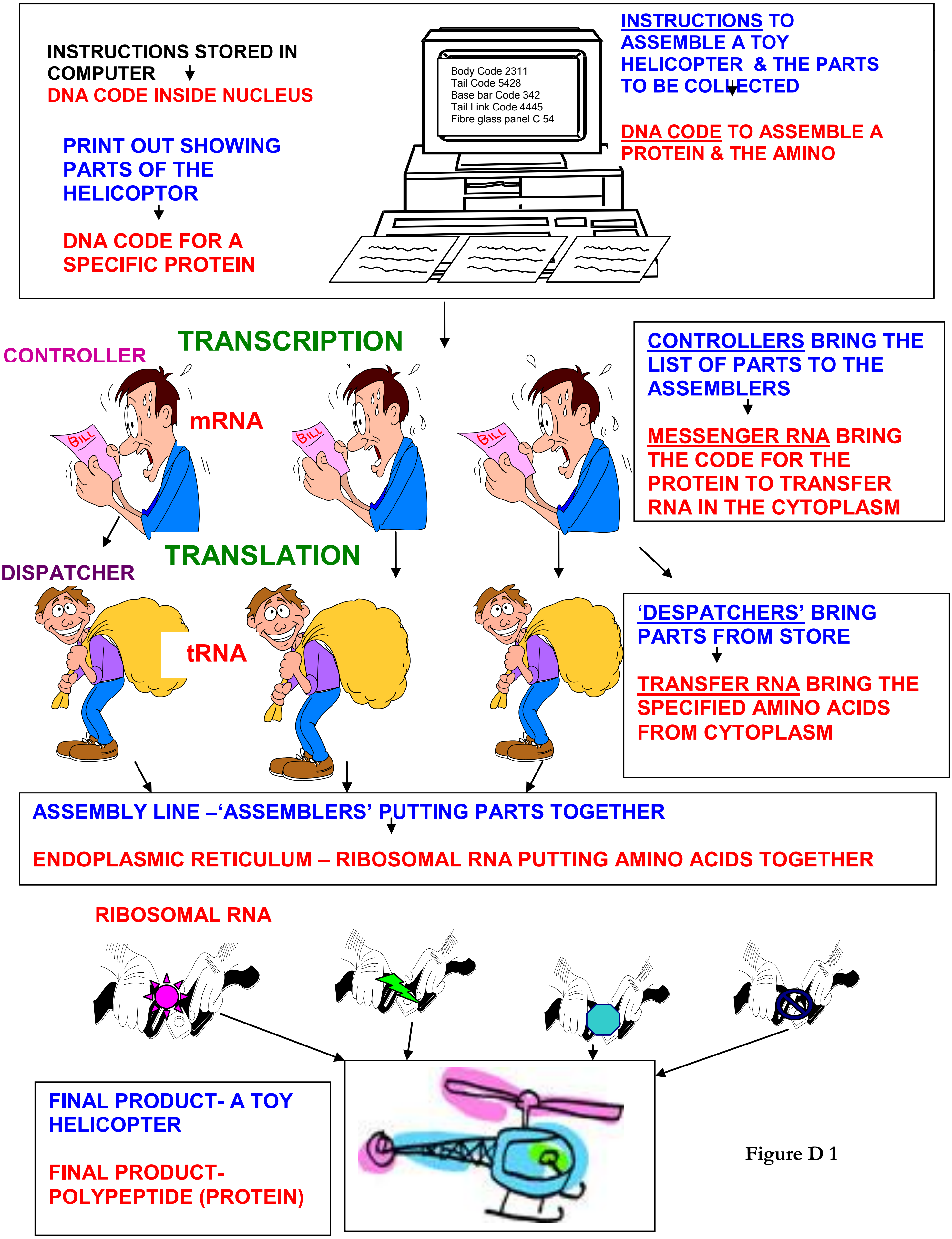


Figure D 1

APPENDIX D. 2

The FAR Guide for Teaching and Learning Protein Synthesis

Focus

Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept 'Protein Synthesis' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept, though they are in year 12.
	Analog	The students are familiar with the chosen analog, which is a toy factory assembly unit.

Action

Likes	Discuss the features of analog and the science concept. Draw similarities between them.	The various steps in the synthesis of proteins could be compared to a factory where specific parts are assembled into a final product. (The details are given below).
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the actual process of protein synthesis largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Similarities mapped out in detail

ANALOG	ANALOG - FEATURES	TARGET
A Toy Factory Assembly Unit	A toy helicopter is manufactured in this unit by assembling many parts together.	The Living Cell, where different kinds of proteins are synthesized by putting amino acids together.
Control room where the computer is kept. The computer has the design and details of the parts for the product, which is the toy helicopter.	The computer contains all the information, such as the size and colour of the parts, their codes and the instruction for assembling the parts, which will produce the toy helicopters in the end.	Nucleus where the DNA is placed; DNA contains the codes for all the amino acids, which when assembled as per the instruction will give the polypeptide chain (protein).
The controller brings the design and the assembling instructions out of the control room to the assembly area.	The print out contains all the details of the parts and the instructions to assemble them.	Messenger RNA bringing the codes for the amino acids out of the nucleus to the cytoplasm.
The controller gives the print out to the dispatcher so that he could collect the parts from the store.	The dispatcher gets the list of parts and instructions for the toy helicopter and collects the parts from the store.	Transfer RNA collects the amino acids from the cytoplasm as per the codes given by the Messenger RNA.
The assemblers (1, 2, 3, 4. . .) receive the parts from the dispatcher and assemble them according to the codes received.	The assemblers are placed along the assembly line. They receive the instructions and the specified parts and assemble them to get the final product, the toy helicopter.	The ribosomal RNA molecules receive the amino acids brought by the tRNA and assemble them into a polypeptide chain, the needed protein.

Reflection

Conclusions	Was the analog clear and useful or confusing?	The analog seemed to be clear and useful. The students were quite excited when they found out that the process was not so complex as it once appeared when it was initially taught, it is as simple as assembling a toy helicopter. The different proteins are formed when the assembly changed. They found it very interesting when they realised that a toy helicopter could be holding a tail on top instead of the rotor, if the assembly went wrong. The same could happen to living, if the instructions for the assembly of proteins went wrong. Many brought out their own analogies along the same line.
Improvements	Refocus in the light of outcomes.	The analog will be refocused in the light of the above outcomes.

APPENDIX D. 3

Two-Tier Diagnostic Instrument on the Understanding of Protein Synthesis in cells

Procedure and Instrumentation [based on the procedure described by Treagust (1986)]

What do you know about protein synthesis in cells?

The following pages contain 10 questions about protein synthesis in the cells of living organisms. Each question has two parts: A Multiple Choice Response followed by a Multiple Choice Reason. You are asked to make one choice from both the Multiple Choice Response section and one choice from the Multiple Choice Reason section for each question.

If you have another reason for your answer, write in the space provided as well as making the choice letter in the reason box.

Answer all questions on the separate answer sheet

1. Read each question carefully.

2. Take time to calculate and consider your answer.

3. Record your answer in the correct box on the answer sheet.

e.g. Q.5 $\boxed{2}$ Reason $\boxed{}$

4. Read the set of possible reasons for your answer.

5. Carefully select a reason, which best matches your thinking when you work out the answer.

6. Record your answer in the correct reason box on the Answer sheet.

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{C}$

7. If you change your mind about an answer, cross out the old answer and add the new choice.

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{\xcancel{C}}$ A

8. If you wish to provide your own reason for the question, write your reason on the sheet in the space provided (d).

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{}$ d) ___________________________

Don't forget to record your name and other details on your Answer sheet.

What do you know about protein synthesis in living organisms?

1. What is the importance of protein synthesis in living organisms?
Your response:
1) Living organisms take protein as an important constituent of balanced diet.
2) Proteins are the largest molecules of living organisms.
3) Without protein synthesis, life processes cannot be carried out in organisms.
4) Any other of your own ____

Your Reason for the response:
a) All the living organisms take in protein in their diet.
b) Many organisms are extinct now, because they didn't take in enough proteins.
c) Proteins are the regulatory structures, which control life processes.

2. Where are the proteins produced in human body?
Your Response:
1) The gland cells in human body produce proteins.
2) All the cells in human body synthesise proteins.
3) Liver produces all the proteins needed for human body.
4) Any other of your own: ____

Your Reason for the response:
a) Every living cell has the potential to produce proteins.
b) The gland cells alone can produce secretions.
c) Digestive system synthesises proteins.

3. What are the basic molecular units that make up a protein?
Your Response:
1) Amino acids are the basic molecular units of protein.
2) Meat, egg, fish and other similar foods form the basic molecular units of protein.
3) Carbon, Hydrogen, Nitrogen and Oxygen are the basic molecular units of protein.
4) Any other of your own ____

Your Reason for the response:
a) Matter is made of atoms and molecules.
b) People are asked to eat meat, egg and fish every day.
c) Proteins, when digested break down to amino acids.

4. What initiates/starts the synthesis of proteins?
Your Response:
1) Eating plenty of different kinds of proteins initiate the synthesis of proteins.
2) Need for a specific protein in a cell or body can initiate the process.
3) Lack of protein in the diet initiates the synthesis of proteins by the body.
4) Any other of your own ____

Your Reason for the response:
a) We add different kinds of proteins in our diet.
b) Proteins perform many vital tasks in a living organism.
c) If we don't eat proteins, it is our body that produces proteins.

5. What is the first step in the synthesis of proteins?
Your Response:

1) The concerned cells identify the need for the synthesis of the specific protein.
2) The RNA molecules identify the need for the synthesis of a specific protein.
3) The DNA molecules identify the need for the synthesis of a specific protein.
4) Any other of your own: ____

Your Reason for the response:

a) The DNA found in cells split to offer a template for the protein to be synthesised.
b) The RNA molecules split to form a template for the protein to be synthesised.
c) The entire body is on alert to form a template for the protein to be synthesised.

6. Name the molecules, which are produced as a result of the above process.
Your Response:

1) Messenger Amino acid molecules.
2) Messenger RNA molecules.
3) Messenger DNA molecules.
4) Any other of your own: ____

Your Reason for the response:

a) Many amino acid molecules act as messengers in our body.
b) The RNA molecules, coded for a protein, act as messengers.
c) The DNA molecules replicate and act as messengers for a protein.

7. What do these molecules do when they are released?
Your Response:

1) These molecules move out of the nucleus.
2) These molecules get attached to a DNA strand.
3) These molecules move into the nucleolus.
4) Any other of your own: ____

Your Reason for the response:

a) These molecules carry out their assignment in the cytoplasm.
b) These molecules change into DNA.
c) Nucleolus helps to synthesise proteins.

8. What is the next step in this process of synthesising proteins?
Your Response:

1) The above molecules transfer the code to mitochondria.
2) The above molecules transfer the code to amino acid molecules.
3) The above molecules transfer the code for the proteins to tRNA.
4) Any other of your own : ____

Your Reason for the response:

a) These molecules are ready to collect the amino acid molecules.
b) These molecules convey the message to the next set of molecules.
c) These molecules give energy to Mitochondria to synthesise proteins.

9. What is the next step in the synthesis of proteins?
Your Response:
1) The transcription of the code and collection of translated RNA.
2) The translation of the code and collection of amino acids transcribed in the code.
3) The translation of the code and collection of transfer RNA transcribed in the code.
4) Any other of your own; ____

Your Reason for the response:
a) Amino acids are needed for the next step in the process of protein synthesis.
b) The RNA molecules are needed for the next step in the process of protein synthesis.
c) The transfer RNA molecules are needed for the next step in the process of protein synthesis.

10. What happens once the above step is completed?
Your Response:
1) The amino acids are moved to the ribosomal site for further assembly.
2) The RNA molecules are moved to the ribosomal site for further assembly.
3) The DNA molecules are moved to the ribosomal site for further assembly.
4) Any other of your own: ____

Your Reason for the response:
a) The ribosomal DNA put the molecules together and synthesise the protein.
b) The ribosomal RNA put the amino acid molecules together and synthesise the protein.
c) The cytoplasmic RNA put the molecules together and synthesise the protein.

What do you know about protein synthesis in living organisms?

ANSWER SHEET

Name ______________________________ Class: ________________________

Date: ______________ Male: __________ Female: _________ Age: __________________

Q. 1 Answer	☐	Q.1 Reason	☐
Q. 2 Answer	☐	Q.2 Reason	☐
Q. 3 Answer	☐	Q.3 Reason	☐
Q. 4 Answer	☐	Q.4 Reason	☐
Q. 5 Answer	☐	Q.5 Reason	☐
Q. 6 Answer	☐	Q.6 Reason	☐
Q. 7 Answer	☐	Q.7 Reason	☐
Q. 8 Answer	☐	Q.8 Reason	☐
Q. 9 Answer	☐	Q.9 Reason	☐
Q. 10 Answer	☐	Q.10 Reason	☐

ANSWERS

Name ______________________ Class: ______________________

Date: ____________ Male: ________ Female: ________ Age: ________

	ANSWER	REASON	Give your own reason here, if you consider the given reasons NOT satisfactory
1.	3	c	1. ____________
.2	2	a	2. ____________
.3	1	c	3. ____________
4.	2	b	4. ____________
5.	3	a	5. ____________
6.	2	b	6. ____________
7.	1	a	7. ____________
8.	3	b	8. ____________
9.	2	a	9. ____________
10.	1	b	10. ____________

APPENDIX D. 4

Table D. 1 Analysis of the individual responses

	Concept - Protein Synthesis	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.1	**What is the importance of protein synthesis in living organisms?**			
Correct Answer	**3. Without protein synthesis, life processes cannot be carried out in organisms.**	56	80	24
Misconception	1. Living organisms take protein as an important constituent of balanced diet.	32	16	-16
Misconception	2. Proteins are the largest molecules of living organisms.	12	4	-8
Correct Reason	**c) Proteins are the regulatory structures, which control life processes.**	68	88	20
Misconception	a) All the living organisms take in protein in their diet.	28	8	-20
Misconception	b) Many organisms are extinct now, because they didn't take in enough proteins.	4	4	0
Q.No.2	**Where are the proteins produced in human body?**			
Correct Answer	**2. All the cells in human body synthesise proteins.**	64	60	-4
Misconception	1.The gland cells in human body produce proteins.	16	12	-4
Misconception	3. Liver produces all the proteins needed for human body.	20	28	8
Correct Reason	a) Every living cell has the potential to produce proteins.	48	68	20
Misconception	b) The gland cells alone can produce secretions.	8	32	24
Misconception	c) Digestive system synthesises proteins.	40	0	-40
Misconception		4	0	-4
Q.No.3	**What are the basic molecular units that make up a protein?**			
Correct Answer	**1) Amino acids are the basic molecular units of protein.**	48	76	28
Misconception	2) Meat, egg, fish and other similar foods form the basic molecular units of protein.	28	8	-20
Misconception	3) Carbon, Hydrogen, Nitrogen and Oxygen are the basic molecular units of protein.	24	16	-8
Correct Reason	**c) Proteins, when digested break down to amino acids.**	64	76	12
Misconception	a) Matter is made of atoms and molecules.	12	20	8
Misconception	b) People are asked to eat meat, egg and fish every day.	24	4	-20

6. 2. 3. Analysis of Individual Responses in the Test

Q.1. What is the importance of protein synthesis in living organisms?

Correct answer: 3. Without protein synthesis, life processes cannot be carried out in organisms.

There was an increase of 24% from the pretest average after the presentation of the analogy and the posttest average was 80%. This indicates that the students were benefited from the analogy, which helped in better understanding.

1. Living organisms take protein as an important constituent of balanced diet.

Though there was a decrease of 16% in this alternate conception, this alternate conception was still held by16% of the students.

2. Proteins are the largest molecules of living organisms.

There was a decrease of 8% in this misconception, but still held by 4% of the students.

Correct reason: c. Proteins are the regulatory structures, which control life processes.

There was an increase of 20% from the pretest after the presentation of the analogy and the posttest average 88%.

a) All the living organisms take in protein in their diet.

This misconception was reduced by 20% in the posttest average and was held by 8% of the students.

b) Many organisms are extinct now, because they didn't take in enough proteins.

This misconception was reduced by 4% and none held this misconception after the presentation of the analogy.

Q.2. **Where are the proteins produced in human body?**

Correct answer: 2. All the cells in human body synthesize proteins.

There was a decrease of 4% in the posttest average and the posttest average was 60%. This indicates that 4% of the students developed misconceptions after the presentation of the analogy. This concept was clarified during the posttest review.

1.The gland cells in human body produce proteins.

This misconception was held by 12%, though there was a decrease of this misconception in the posttest average by 4%.

3. Liver produces all the proteins needed for human body.

Once again 8% of the students developed this misconception after the presentation of the analogy, which was unfortunate. All the choices were dealt with in detail during the posttest review to enable better understanding of the concept.

Correct reason: a) Every living cell has the potential to produce proteins.

There was an increase of 20% in the posttest average, which indicates that the analogy was helpful; to understand the concept. The posttest average was 68%.

b) The gland cells alone can produce secretions.

This alternate conception was held by 32% of the students, an increase of 24% from the pretest average. The preconception that glands are associated with secreting substances for the body did have an influence on accepting the fact that every cell can secrete substances.

c) Digestive system synthesizes proteins.

This misconception was held by 40% of the students, but was completely removed after the presentation of the analogy and none chose the answer in the posttest.

Q. 3. What are the basic molecular units that make up a protein?

Correct answer: 1) Amino acids are the basic molecular units of protein.

This correct answer was chosen by 76%, an increase of 28% from the pretest indicating that the analogy helped in understanding of the concept.

2) Meat, egg, fish and other similar foods form the basic molecular units of protein.

This answer was chosen by 28% of the cohort, but after the presentation of the analogy, only 8% chose this answer. A decrease of 20% in the average indicates that the analogy did help in the correct perception of the concept.

3) Carbon, Hydrogen, Nitrogen and Oxygen are the basic molecular units of protein.

Though there was a decrease of 8% in the posttest average, though this alternate conception was still held by 16% of the students. Confusion between atoms and molecules caused this incorrect perception, which was addressed during the posttest review.

Correct reason: c) Proteins, when digested break down to amino acids.

This answer was chosen by

a) Matter is made of atoms and molecules

This alternate conception was held by 20% of the students because they were not sure about the nature of the molecules which make up proteins. This explained to them during the posttest review.

b) People are asked to eat meat, egg and fish every day.

This reason supports Answer 2 given above. After the presentation of the analogy, there was a decrease of 20% in the posttest test average and only 4% held this misconception.

Table D. ! Continued . . .	Concept - Protein Synthesis	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.4	What initiates/starts the synthesis of proteins?			
Correct Answer	2. Need for a specific protein in a cell or body can initiate the process.	68	72	4
Misconception	1. Eating plenty of different kinds of proteins initiate the synthesis of proteins.	20	20	0
Misconception	3. Lack of protein in the diet initiates the synthesis of proteins by the body.	12	8	-4
Correct Reason	b) Proteins perform many vital tasks in a living organism.	72	76	4
Misconception	a) We add different kinds of proteins in our diet.	24	16	-8
Misconception	c)If we don't eat proteins, it is our body that produces proteins.	0	8	8
Misconception	Students' own	4	0	-4
Q.No.5	What is the first step in the synthesis of proteins?			
Correct Answer	3. The DNA molecules identify the need for the synthesis of a specific protein.	40	68	28
Misconception	1. The concerned cells identify the need for the synthesis of the specific protein.	16	24	8
Misconception	2. The RNA molecules identify the need for the synthesis of a specific protein.	44	8	-36
Correct Reason	a) The DNA found in cells split to offer a template for the protein to be synthesised.	40	60	20
Misconception	b) The RNA molecules split to form a template for the protein to be synthesised.	40	16	-24
Misconception	c) The entire body is on alert to form a template for the protein to be synthesised.	20	24	4
Q.No.6	Name the molecules, which are produced as a result of the above process.			
Correct Answer	2. Messenger RNA molecules.	60	76	16
Misconception	1. Messenger Amino acid molecules.	24	16	-8
Misconception	3. Messenger DNA molecules.	16	8	-8
Correct Reason	b. The RNA molecules, coded for a protein, act as messengers.	60	80	20
Misconception	a. Many amino acid molecules act as messengers in our body.	24	12	-12
Misconception	c. The DNA molecules replicate and act as messengers for a protein.	16	8	-8
Q.No.7	What do these molecules do when they are released?			
Correct Answer	1) These molecules move out of the nucleus.	40	52	12
Misconception	2) These molecules get attached to a DNA strand.	40	28	-12
Misconception	3) These molecules move into the nucleolus.	20	20	0
Correct Reason	a) These molecules carry out their assignment in the cytoplasm.	52	56	4
Misconception	b) These molecules change into DNA.	20	24	4
Misconception	c) Nucleolus helps to synthesise proteins.	28	20	-8

Q.4. What initiates/starts the synthesis of proteins?

Correct answer: 2. Need for a specific protein in a cell or body can initiate the process.

There was a marginal increase of 4% in the posttest and this indicated that the analogy benefited the students to a certain extent. 72% of the students held this correct conception.

1. Eating plenty of different kinds of proteins initiate the synthesis of proteins.

Though 20% of the students held this conception, there were none, who chose this answer in the posttest and this indicates that the analogy clarified this point for them

3. Lack of protein in the diet initiates the synthesis of proteins by the body.

Only 8% of the students held this misconception after the presentation of the analogy and this was clarified during the posttest review.

Correct Reason: b) Proteins perform many vital tasks in a living organism

This conception was held by 76% of the students after the analogy was presented to them and this was an increase of 4% from the posttest average.

a) We add different kinds of proteins in our diet.

The idea that an intake of different kinds of protein could initiate the synthesis of proteins was held by 16%, even after the presentation of the analogy, though the posttest showed a decrease of 8% in the average. This was clarified later.

c) If we don't eat proteins, it is our body that produces proteins.

This misconception was created and held after the presentation of the analogy, which is an anomaly. This misunderstanding was cleared during the posttest review.

Q.5 What is the first step in the synthesis of proteins?

Correct answer: 3. The DNA molecules identify the need for the synthesis of a specific protein.

There was an increase of 28% after the presentation of the analogy, which indicates that the analogy helped to enhance the understanding of the concept.

1. The concerned cells identify the need for the synthesis of the specific protein.

This alternate conception was held by 24% of the students and this was explained to them later cleared during the posttest review.

2. The RNA molecules identify the need for the synthesis of a specific protein.

The analogy clearly indicated the hierarchical organization of the communication path. This must have helped in understanding the role played by the DNA and RNA molecules to a large extent. The posttest average showed that there was a decrease of 36% after the presentation of the analogy.

Correct Reason: a) The DNA found in cells split to offer a template for the protein to be synthesised.

There was an increase of 20% in the posttest average showing that the analogy helped to understand the concept better. 60% of the students chose this answer.

b) The RNA molecules split to form a template for the protein to be synthesised.

There was a decrease of 24% from the pretest average after the analogy was presented. Yet, there were 16% who held this alternate conception and their doubts were clarified.

c) The entire body is on alert to form a template for the protein to be synthesised.

This alternate conception was held by 24% even after the analogy was presented. This was taken up for discussion and the students' doubts were clarified.

Q.6 Name the molecules, which are produced as a result of the above process.

Correct Answer: 2. Messenger RNA molecules.

There was an increase of 16% in the posttest and 76% held this conception after the analogy was presented. The students found the analog of the RNA molecules very funny. Anything abnormal invited more attention from the students and probably helped in better retention.

1. Messenger Amino acid molecules.

The posttest average showed 8% decrease from the pretest average; yet 16% held this alternate conception. The students were advised to spend more time to read and remember the technical terms to avoid this confusion during the posttest review.

3. Messenger DNA molecules.

Posttest average showed that only 8% held this misconception. They were advised that listening and reading their notes alone would help to remember the technical terms.

Correct reasons: b. The RNA molecules, coded for a protein, act as messengers.

There was a 20% increase from the pretest after the presentation of the analogy and 80% chose the correct reason in the posttest.

a. Many amino acid molecules act as messengers in our body.

Though there was a decrease of 12% in the posttest average, this alternate conception was held by 12% of the cohort. This confusion arose due to the absence of listening skills and follow up later. The students were cautioned about this later.

c. The DNA molecules replicate and act as messengers for a protein.

The students who held this misconception were told to listening in class and systematic follow up would help to remember the technical terms.

Q. 7 What do these molecules do when they are released?

Correct Answer: 1) These molecules move out of the nucleus.

The increase of 12% in the posttest average shows that the students were benefited by the analogy.

2) These molecules get attached to a DNA strand.

This alternate conception was held by 28%, though the average is 12% less than the pretest average. This was discussed during the posttest review and doubts were clarified.

3) These molecules move into the nucleolus.

None believed that this happened after the presentation of the analogy and all the 20% who chose this reason in the pretest changed their view.

Correct Reason: a) These molecules carry out their assignment in the cytoplasm.

There was a marginal increase in the posttest average and 56% believed in this concept. The students found it a bit difficult to associate the cell process with actual happening at the toy factory, though the computer room corresponded with the nucleus and the assembling area corresponded with the cytoplasm.

b) These molecules change into DNA.

Strangely, the posttest average increased by 4% from the pretest and it was clear during the posttest review that they were not sure of the technical terms. Revising the notes to remember the technical terms was explained to them.

c) Nucleolus helps to synthesise proteins.

This is not a relevant answer for the question, but 20% of the students chose this answer. The analog did not have anything relating to nucleolus.

I found out from the two-tier tests that lack of understanding of technical terms was affecting their understanding and retentive ability and consequently their achievement. After presenting the analogy of crossing over and protein synthesis and the review of the posttests, I decided to spend a few minutes every week to teach them Greek and Latin roots of scientific terms. I gave them twenty words every time. The students and I split the words into prefixes, base words and suffixes, wherever possible. Then, I asked them to call out words from their memory, which contained the same prefixes or suffixes. For example, if I had taught them the meaning of the word, 'hyper', my students had to call out words like: hyperactive, hyperglycaemia, hypertonic, etc. Once the word list was exhausted, the students were asked to generate ten words using the prefixes or suffixes that we had learnt on that day. This proved to be very effective in retaining scientific terms for a longer period. I repeated this every year to enhance my biology students' achievement levels.

Table D. 1 Continued . . .	Concept - Protein Synthesis	Average % Pretest	Posttest	Increase/ Decrease
Question. 8	What is the next step in this process of synthesising proteins?			
Correct Answer	3. The above molecules transfer the code for the proteins to tRNA	60	72	12
Misconception	1) The above molecules transfer the code to mitochondria.	24	12	-12
Misconception	2) The above molecules transfer the code to amino acid molecules.	16	16	0
Correct Reason	b) These molecules convey the message to the next set of molecules.	44	68	24
Misconception	a) These molecules are ready to collect the amino acid molecules.	20	20	0
Misconception	c) These molecules give energy to Mitochondria to synthesise proteins.	36	12	-24
Question. 9	What is the next step in the synthesis of proteins?			
Correct Answer	2) The translation of the code and collection of amino acids transcribed in the code.	40	40	0
Misconception	1) The transcription of the code and collection of translated RNA.	44	44	0
Misconception	3) The translation of the code and collection of transfer RNA transcribed in the code.	16	16	0
Correct Reason	a) Amino acids are needed for the next step in the process of protein synthesis.	36	32	-4
Misconception	c) The transfer RNA molecules are needed for the next step in the process of protein synthesis.	28	40	12
	b) The RNA molecules are needed for the next step in the process of protein synthesis.	36	28	-8
Question. 10	What happens once the above step is completed?			
Correct Answer	1) The amino acids are moved to the ribosomal site for further assembly.	72	40	-32
Misconception	2) The RNA molecules are moved to the ribosomal site for further assembly.	20	32	12
Misconception	3) The DNA molecules are moved to the ribosomal site for further assembly.	8	28	20
Correct Reason	b) The ribosomal RNA put the amino acid molecules together and synthesise the protein.	60	52	-8
Misconception	a) The ribosomal DNA put the molecules together and synthesise the protein	24	40	16
Misconception	c) The cytoplasmic RNA put the molecules together and synthesise the protein.	16	8	-8

Q.8 What is the next step in this process of synthesising proteins?

Correct Answer: 3. The above molecules transfer the code for the proteins to tRNA

There was an increase of 12% in the posttest average and the posttest average was 72% after the presentation of the analogy, which indicated that the analogy was useful.

1) The above molecules transfer the code to mitochondria.

The posttest average showed a decrease of 12%. There were 12% of the students who held this misconception and their doubts were clarified during the posttest review.

2) The above molecules transfer the code to amino acid molecules.

None held this alternate conception after the presentation of the analogy. 16% of the students, who chose this answer in the pretest, changed their answer in the posttest.

Correct Reason: b) These molecules convey the message to the next set of molecules.

This correct reason was chosen by 68% of the students in the posttest. This is 24% increase from the pretest, which shows that the students were benefited by the analogy.

a) These molecules are ready to collect the amino acid molecules.

All the 20% of the students, who chose this answer in the pretest, changed their answer in the posttest after the presentation of the analogy.

c) These molecules give energy to Mitochondria to synthesise proteins.

There was a decrease of 24% in this alternate conception in the posttest and 12% still held this alternate conception. This was clarified during the posttest review.

Q. 9 What is the next step in the synthesis of proteins?

Correct Answer: 2) The translation of the code and collection of amino acids transcribed in the code.

It was interesting to note that there was no change in their perception after presenting the analogy. The pre and posttest averages remained the same. Neither were there any changes in the alternate conceptions!

2) The translation of the code and collection of amino acids transcribed in the code.

As stated earlier, 44% held the above alternate conception prior to and after the presentation of the analogy. The process of protein synthesis had to be reviewed and discussed after the posttest.

3) The translation of the code and collection of transfer RNA transcribed in the code.

This alternate conception was held by 16% of the cohort and their doubts were clarified during the posttest review.

Correct Reason: a) Amino acids are needed for the next step in the process of protein synthesis.

Unfortunately there was a decrease of 4% in the posttest average. Only 32% of the students chose this answer.

c) The transfer RNA molecules are needed for the next step in the process of protein synthesis.

The students were not sure of the answer. It was disappointing to note that 40% of the students held this alternate conception, which actually showed an increase of 12% from the pretest.

b) The RNA molecules are needed for the next step in the process of protein synthesis

This alternate conception was held by 28% of the students after the presentation of the analogy which was taken up for discussion and clarified later.

Q.10 **What happens once the above step is completed?**

Correct Answer: 1) The amino acids are moved to the ribosomal site for further assembly.

Only 40% of the students chose this correct answer and there was a decrease of 32% in the posttest average, which indicated that they were not thorough with the concept, despite the analogy presented. The scientific terms were not understood and remembered in relation to the context and hence the inability to apply, when appropriate.

2) The RNA molecules are moved to the ribosomal site for further assembly.

It was the same problem again as a result of confusion between the new terms learnt. This showed an increase of 12% in the posttest.

3) The DNA molecules are moved to the ribosomal site for further assembly.

This alternate conception held by 28% of the students, shows that the majority of the students had not understood this part of the concept clearly. The process of protein synthesis was explained again with the help of the analogy diagram.

Correct Reason: b) The ribosomal RNA puts the amino acid molecules together and synthesises protein.

Many students probably guessed the correct answer and reason by chance in the pretest. The posttest average of 52% was 8% less than the pretest average, which showed clearly that many students were holding alternate conceptions and this was brought out by the two-tier testing.

a) The ribosomal DNA put the molecules together and synthesise the protein

This alternate conception was held by 40% of the students and posttest average showed an increase of 16%, which further confirmed the students' lack of knowledge and understanding of the concept.

c) The cytoplasmic RNA put the molecules together and synthesise the protein.

This misconception was held by 8% of the students and the posttest average showed a decrease of 8% from the pretest.

Appendix D. 5 a, b, c

Quantitative Analysis

Graph: Two Tier Test Results - Protein Synthesis

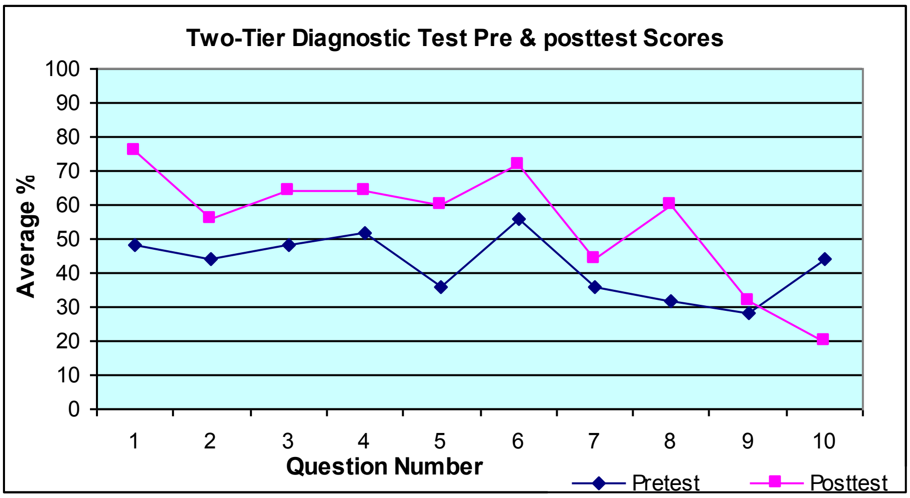


Figure D. 2

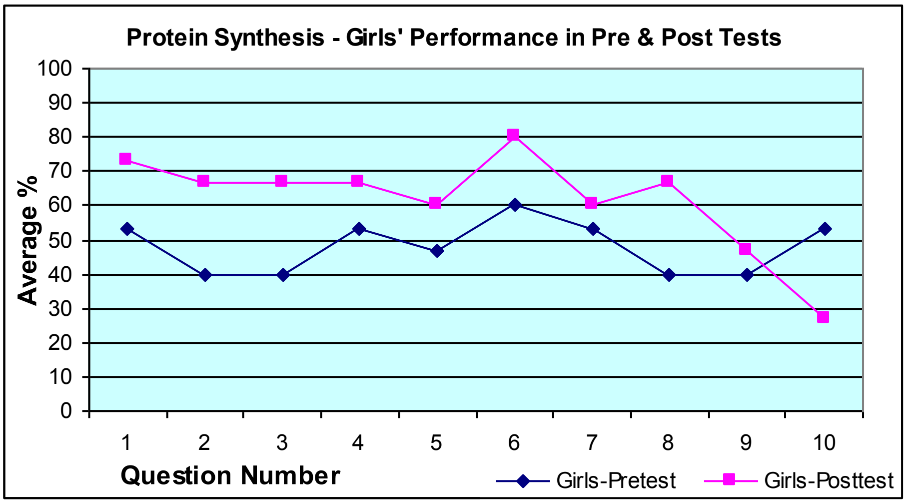


Figure D. 3

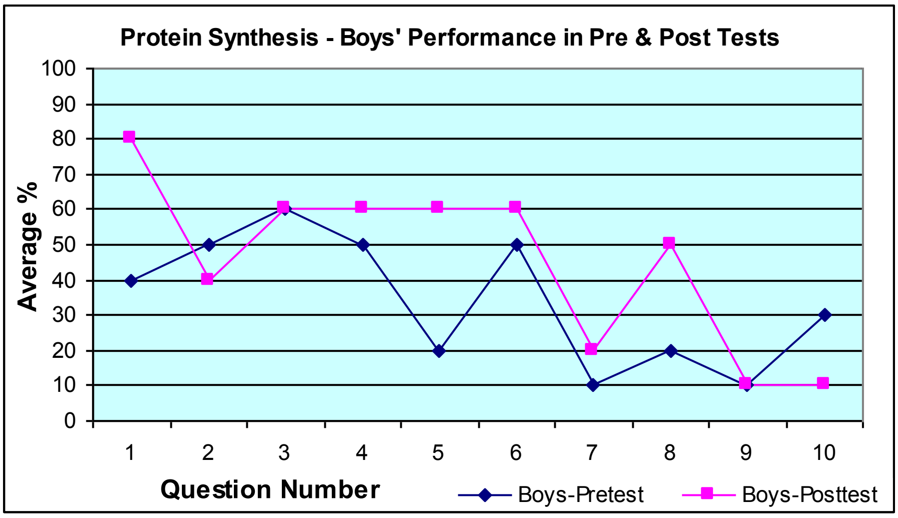


Figure D. 4

APPENDIX D 5. d, e

Two- Tier Diagnostic Test Results based on Gender differences

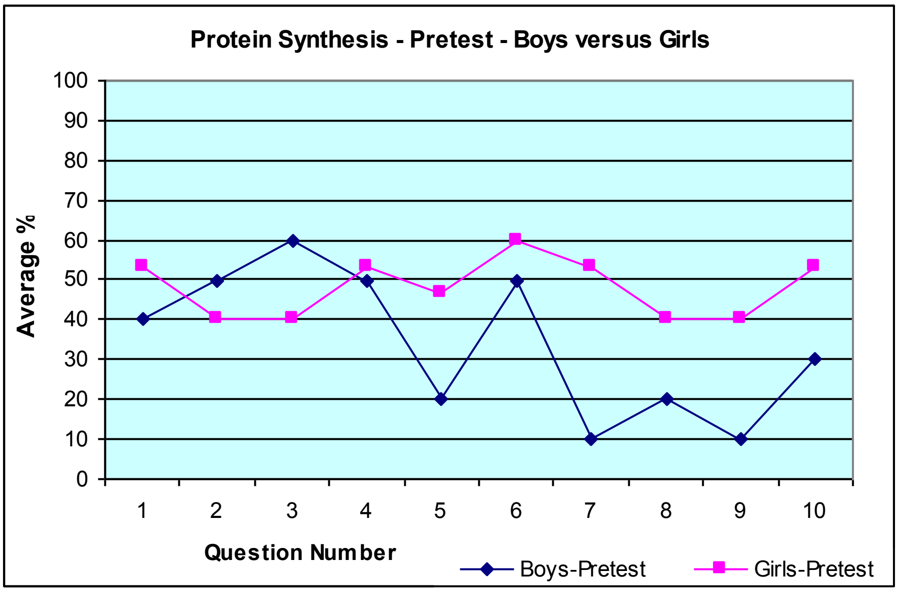


Figure D. 5

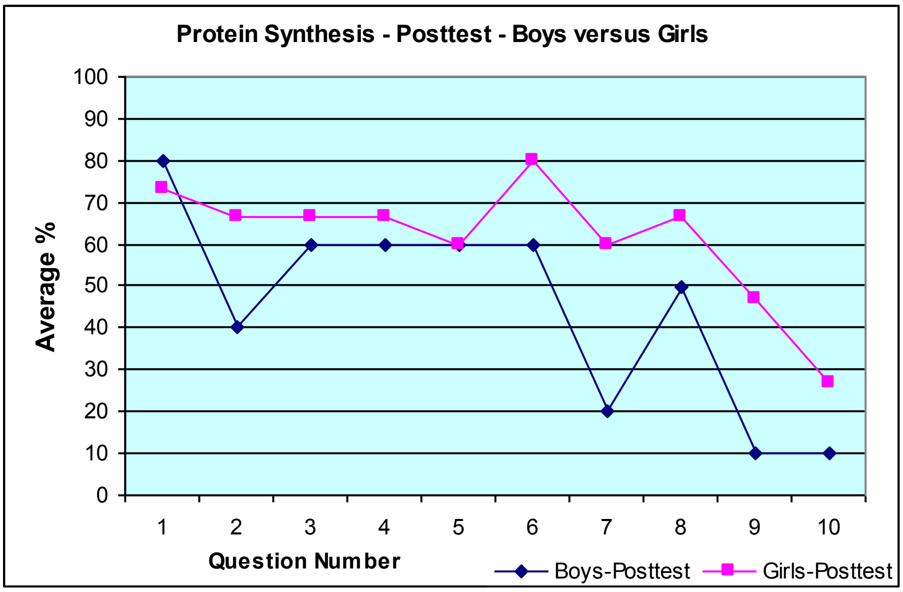


Figure D. 6

APPENDIX D. 6

Protein Synthesis - Preconceptions

Name: ____ Date: __________________

1. Why should proteins be produced in our body?

2. Where are the proteins produced in our body?

3. What initiates the production of proteins?

4. Name the simplest molecular units that make up a protein.

5. What is the first step in the synthesis of protein?

6. What are the molecules that are produced as a result of the above process?

7. Where do these molecules go once they are released?

8. What is their function in this place of their destination?

9. Name the molecular units that respond to their instruction.

10. What is their role in the synthesis of proteins?

11. Name the molecules at the ribosomal site, which participate in the synthesis of proteins.

12. What is the role of the above molecules in the synthesis of proteins?

13. What is the generic term that describes the assembled product at the ribosomal site?

Higher order thinking:

1. What kind of food should be included in one's diet in adequate amounts, if the body were to produce proteins, when ever there is a need?

2. What could happen, if there is no synthesis of proteins in an organism?

3. What will be the outcome, when a part of the chromosome is missing in all the cells of an organism due to a genetic mutation and if this organ were to produce a hormone?

4. Imagine a situation, in which radiation destroys half a chromosome of a sperm cell during meiosis. What can we expect in the offspring if this sperm were to fertilise an egg cell and the embryo survived?

5. How will a human respond to an invasion of bacteria, if the cells in the patient's body do not have the ability to synthesise proteins?

6. Draw a flow chart to show how the cells synthesise proteins.

7. Construct a concept map to show the various functions of proteins in human body

APPENDIX D. 7

Protein Synthesis

Likes and Dislikes; Analog - Target mapping

Likes

Factory Assembly Unit	A living Cell
Room where the computer is kept	Nucleus where the DNA is kept
Blue print for the product in the computer	DNA
Print out of the blue print	Code for the amino acid (mRNA)
Conveyer belt bringing the print out to the surrounding foyer, where the parts are placed and to be assembled	mRNA slipping out of nucleus through the nuclear membrane with the code for the protein to be synthesised.
Worker (1) in the first line of assembly reads the print out and knows the parts, which are to be collected and taken to the assembly table, so do the others in the first assembly line.	tRNA gets the anticodon by attaching itself to the mRNA and knows what amino acids are to be collected and taken to the ribosomal site, so do the other tRNA.
Workers (2) are ready near the assembly table to receive and put the parts together and complete the assembly. The final product is just as it is given in blue print.	Ribosomal RNA molecules receive the amino acids and assemble them as per the code brought by the mRNA and translated by the tRNA. Thus the protein is synthesised.

Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the actual process largely. (the students will be encouraged to bring out their view on this, if any).

Conclusions	Was the analog clear and useful or confusing?
Improvements	How can we improve the analogy for better understanding?

What is your opinion on teaching with analogies to make certain scientific concepts easy?

Can you given an analogy of your own instead of the helicopter manufacturing factory, which works in a similar way to protein synthesis?

APPENDIX D 8

PROTEIN SYNTHESIS - FREQUENCIES

Frequency Tables

PRETEST

Q1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	1	4.0	4.0	16.0
	1c	4	16.0	16.0	32.0
	2a	2	8.0	8.0	40.0
	2c	1	4.0	4.0	44.0
	3a	2	8.0	8.0	52.0
	3c	12	48.0	48.0	100.0
	Total	25	100.0	100.0	

Q2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.0	4.0	4.0
	1b	1	4.0	4.0	8.0
	1c	2	8.0	8.0	16.0
	2a	11	44.0	44.0	60.0
	2b	1	4.0	4.0	64.0
	2c	4	16.0	16.0	80.0
	3c	4	16.0	16.0	96.0
	3d	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Q3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1c	12	48.0	48.0	48.0
	2b	5	20.0	20.0	68.0
	2c	2	8.0	8.0	76.0
	3a	3	12.0	12.0	88.0
	3b	1	4.0	4.0	92.0
	3c	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

Q4pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	2	8.0	8.0	20.0
	2a	3	12.0	12.0	32.0
	2b	13	52.0	52.0	84.0
	2d	1	4.0	4.0	88.0
	3b	3	12.0	12.0	100.0
	Total	25	100.0	100.0	

Q5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	1	4.0	4.0	4.0
	1c	3	12.0	12.0	16.0
	2a	1	4.0	4.0	20.0
	2b	8	32.0	32.0	52.0
	2c	2	8.0	8.0	60.0
	3a	9	36.0	36.0	96.0
	3b	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Q6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	5	20.0	20.0	20.0
	1b	1	4.0	4.0	24.0
	2b	14	56.0	56.0	80.0
	2c	1	4.0	4.0	84.0
	3a	1	4.0	4.0	88.0
	3c	3	12.0	12.0	100.0
	Total	25	100.0	100.0	

Q7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	9	36.0	36.0	36.0
	1c	1	4.0	4.0	40.0
	2a	3	12.0	12.0	52.0
	2b	5	20.0	20.0	72.0
	2c	2	8.0	8.0	80.0
	3a	1	4.0	4.0	84.0
	3c	4	16.0	16.0	100.0
	Total	25	100.0	100.0	

Q8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.0	4.0	4.0
	1b	1	4.0	4.0	8.0
	1c	4	16.0	16.0	24.0
	2a	1	4.0	4.0	28.0
	2b	2	8.0	8.0	36.0
	2c	1	4.0	4.0	40.0
	3a	3	12.0	12.0	52.0
	3b	8	32.0	32.0	84.0
	3c	4	16.0	16.0	100.0
	Total	25	100.0	100.0	

Q9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	5	20.0	20.0	32.0
	1c	3	12.0	12.0	44.0
	2a	6	24.0	24.0	68.0
	2b	3	12.0	12.0	80.0
	2c	1	4.0	4.0	84.0
	3b	1	4.0	4.0	88.0
	3c	3	12.0	12.0	100.0
	Total	25	100.0	100.0	

Q10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	5	20.0	20.0	20.0
	1b	11	44.0	44.0	64.0
	1c	2	8.0	8.0	72.0
	2b	3	12.0	12.0	84.0
	2c	2	8.0	8.0	92.0
	3a	1	4.0	4.0	96.0
	3b	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

POSTTEST

Q1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.0	4.0	4.0
	1b	1	4.0	4.0	8.0
	1c	2	8.0	8.0	16.0
	2c	1	4.0	4.0	20.0
	3a	1	4.0	4.0	24.0
	3c	19	76.0	76.0	100.0
	Total	25	100.0	100.0	

Q2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	8.0	8.0	8.0
	1c	1	4.0	4.0	12.0
	2a	14	56.0	56.0	68.0
	2c	1	4.0	4.0	72.0
	3a	1	4.0	4.0	76.0
	3c	6	24.0	24.0	100.0
	Total	25	100.0	100.0	

Q3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1c	16	64.0	64.0	76.0
	2b	1	4.0	4.0	80.0
	2c	1	4.0	4.0	84.0
	3a	2	8.0	8.0	92.0
	3c	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

Q4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	2	8.0	8.0	20.0
	2b	16	64.0	64.0	84.0
	2c	2	8.0	8.0	92.0
	3a	1	4.0	4.0	96.0
	3b	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Q5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	2	8.0	8.0	8.0
	1c	4	16.0	16.0	24.0
	2b	2	8.0	8.0	32.0
	3a	15	60.0	60.0	92.0
	3c	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

Q6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	1	4.0	4.0	16.0
	2b	18	72.0	72.0	88.0
	2c	1	4.0	4.0	92.0
	3b	1	4.0	4.0	96.0
	3c	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Q7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	11	44.0	44.0	44.0
	1c	2	8.0	8.0	52.0
	2a	2	8.0	8.0	60.0
	2b	5	20.0	20.0	80.0
	3a	1	4.0	4.0	84.0
	3b	1	4.0	4.0	88.0
	3c	3	12.0	12.0	100.0
	Total	25	100.0	100.0	

Q8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.0	4.0	4.0
	1c	2	8.0	8.0	12.0
	2a	2	8.0	8.0	20.0
	2b	2	8.0	8.0	28.0
	3a	2	8.0	8.0	36.0
	3b	15	60.0	60.0	96.0
	3c	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Q9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	8.0	8.0	8.0
	1b	3	12.0	12.0	20.0
	1c	6	24.0	24.0	44.0
	2a	6	24.0	24.0	68.0
	2b	2	8.0	8.0	76.0
	2c	2	8.0	8.0	84.0
	3b	2	8.0	8.0	92.0
	3c	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

Q10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	12.0	12.0	12.0
	1b	5	20.0	20.0	32.0
	1c	2	8.0	8.0	40.0
	2a	1	4.0	4.0	44.0
	2b	7	28.0	28.0	72.0
	3a	6	24.0	24.0	96.0
	3b	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

Item1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	13	52.0	52.0	52.0
	1	12	48.0	48.0	100.0
	Total	25	100.0	100.0	

Item2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	14	56.0	56.0	56.0
	1	11	44.0	44.0	100.0
	Total	25	100.0	100.0	

PRETEST

Item3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	13	52.0	52.0	52.0
	1	12	48.0	48.0	100.0
	Total	25	100.0	100.0	

Item4pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	12	48.0	48.0	48.0
	1	13	52.0	52.0	100.0
	Total	25	100.0	100.0	

Item5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	16	64.0	64.0	64.0
	1	9	36.0	36.0	100.0
	Total	25	100.0	100.0	

Item6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	11	44.0	44.0	44.0
	1	14	56.0	56.0	100.0
	Total	25	100.0	100.0	

Item7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	16	64.0	64.0	64.0
	1	9	36.0	36.0	100.0
	Total	25	100.0	100.0	

Item8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	17	68.0	68.0	68.0
	1	8	32.0	32.0	100.0
	Total	25	100.0	100.0	

Item9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	18	72.0	72.0	72.0
	1	7	28.0	28.0	100.0
	Total	25	100.0	100.0	

Item10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	14	56.0	56.0	56.0
	1	11	44.0	44.0	100.0
	Total	25	100.0	100.0	

POSTTEST

Item1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	6	24.0	24.0	24.0
	1	19	76.0	76.0	100.0
	Total	25	100.0	100.0	

Item2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	11	44.0	44.0	44.0
	1	14	56.0	56.0	100.0
	Total	25	100.0	100.0	

Item3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	36.0	36.0	36.0
	1	16	64.0	64.0	100.0
	Total	25	100.0	100.0	

Item4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	36.0	36.0	36.0
	1	16	64.0	64.0	100.0
	Total	25	100.0	100.0	

Item5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	40.0	40.0	40.0
	1	15	60.0	60.0	100.0
	Total	25	100.0	100.0	

Item6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	7	28.0	28.0	28.0
	1	18	72.0	72.0	100.0
	Total	25	100.0	100.0	

Item7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	14	56.0	56.0	56.0
	1	11	44.0	44.0	100.0
	Total	25	100.0	100.0	

Item8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	40.0	40.0	40.0
	1	15	60.0	60.0	100.0
	Total	25	100.0	100.0	

Item9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	17	68.0	68.0	68.0
	1	8	32.0	32.0	100.0
	Total	25	100.0	100.0	

Item10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	20	80.0	80.0	80.0
	1	5	20.0	20.0	100.0
	Total	25	100.0	100.0	

Statistics

		TOTALpre	TOTALpost
N	Valid	25	25
	Missing	0	0
Mean		4.24	5.48
Std. Deviation		2.505	2.238

TOTALpre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	4.0	4.0	4.0
	1	4	16.0	16.0	20.0
	2	1	4.0	4.0	24.0
	3	4	16.0	16.0	40.0
	4	3	12.0	12.0	52.0
	5	5	20.0	20.0	72.0
	6	2	8.0	8.0	80.0
	7	3	12.0	12.0	92.0
	8	1	4.0	4.0	96.0
	10	1	4.0	4.0	100.0
	Total	25	100.0	100.0	

TOTALpost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	2	8.0	8.0	8.0
	3	4	16.0	16.0	24.0
	4	1	4.0	4.0	28.0
	5	4	16.0	16.0	44.0
	6	6	24.0	24.0	68.0
	7	3	12.0	12.0	80.0
	8	3	12.0	12.0	92.0
	9	2	8.0	8.0	100.0
	Total	25	100.0	100.0	

APPENDIX E

(Relates to Chapter 7)

THE QUANTUM MECHANICAL MODEL (ELECTRONIC CONFIGURATION)

APPENDIX E.1

The Quantum Mechanical Model as a Computer Game

Description of the Analogy:

Students were asked to imagine the following:

When the trigger is activated, the boxes open and release the birds. The birds fly one at the time followed by its partner, if there is one. The pair takes their position in the cages placed on the branches according to their energy level. The main lateral branches correspond to the primary energy level and their branches represent the sublevels. The cages are the atomic orbitals, where a bird/electron in an atom is likely to be found. The names of the orbitals correspond to the alphabet of the spinning level. For example,'s' orbital is called the '**S**low' cage, 'p' orbital '**P**ower' cage and 'd' orbital, '**D**art' cages respectively. The flying birds (as seen in the Power Point presentation) caught students' attention straightaway because of the animation. After the Reflection stage, I realised that te students had difficulty in remembering the names of the scientists and their contributions. Therefore, 4 slides were included to enhance student-understanding.

a. Power Point Presentation

Analogy for the Quantum Mechanical Model - Electronic Configuration

Slide 1

THE QUANTUM MECHANICAL MODEL OF THE ATOM

ELECTRON CONFIGURATION

Slide 2

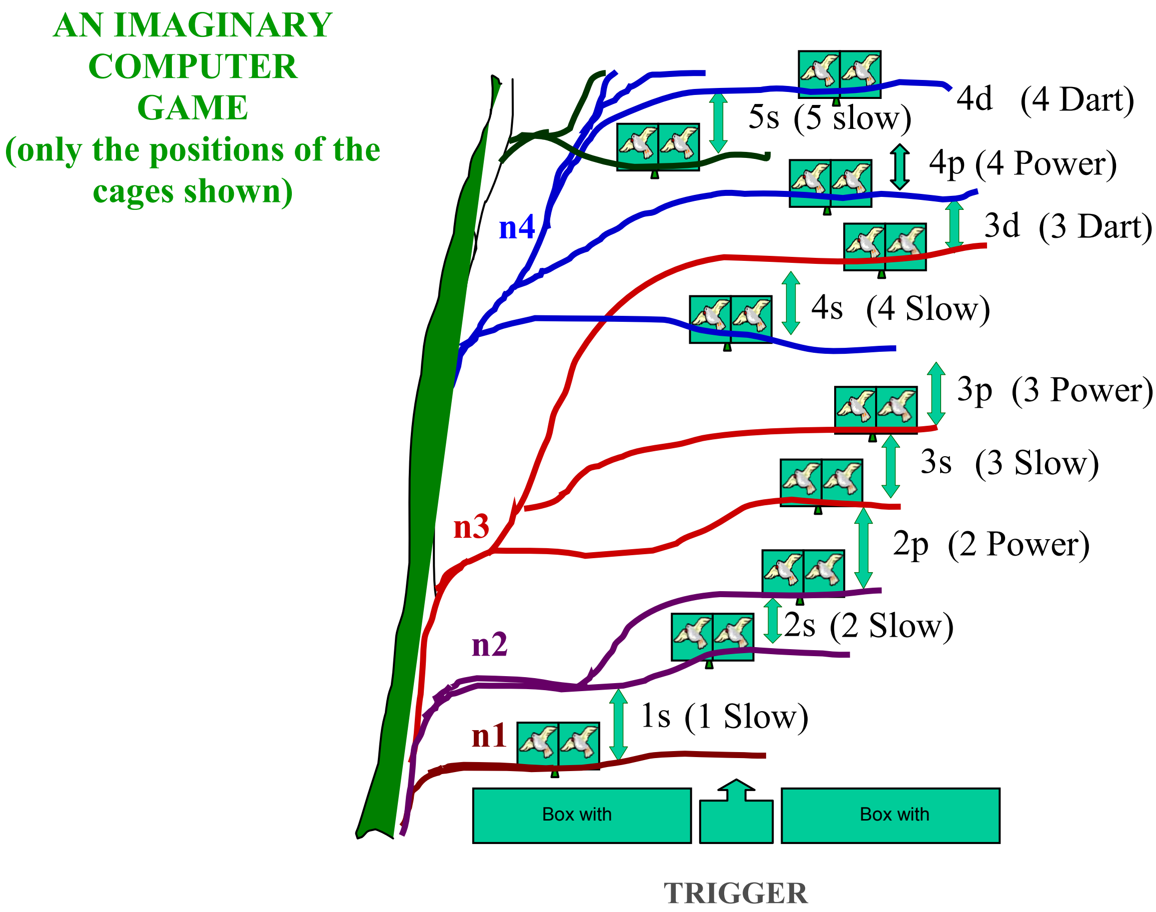


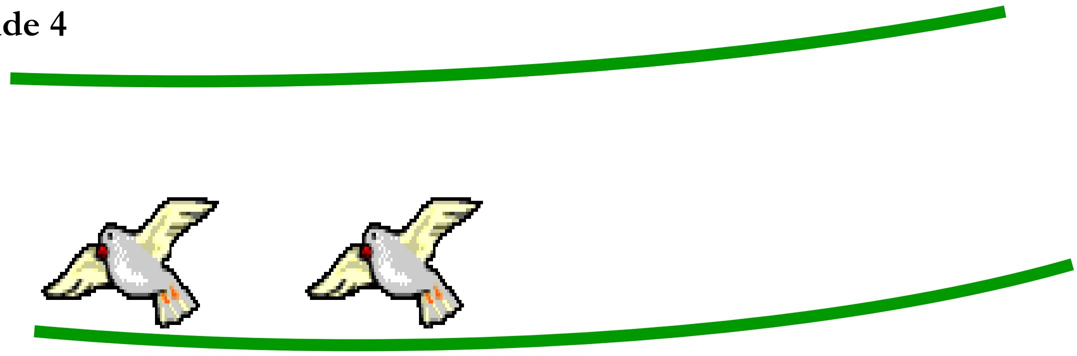
Figure E. 1. a

Slide 3

Electrons and Spinning Birds
(Analogy is an imaginary computer game)

When the trigger is released, the birds take off from the boxes and occupy different cages found between the branches and spin in opposite directions.
The heights they can fly depends on the energy they possess and this decides the cages they occupy.
Birds are compared to electrons, branches, the quantum levels and the cages, the orbitals.

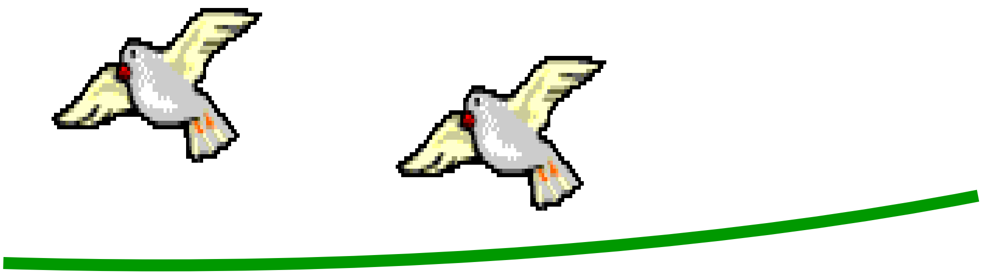
Slide 4



1 Slow cage

Figure E. 1. b

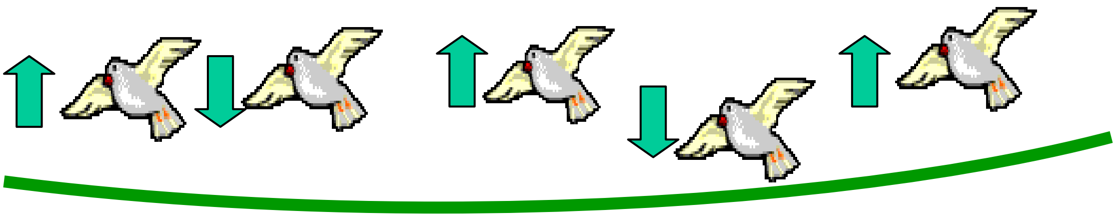
Slide 5



2 Slow cage

Figure E. 1. c.

Slide 6



2 Power cage

One enters the cage first and starts to spin vertically; it is joined by the next, which starts to spin in the opposite direction!

Figure E. 1. d

Slide 7

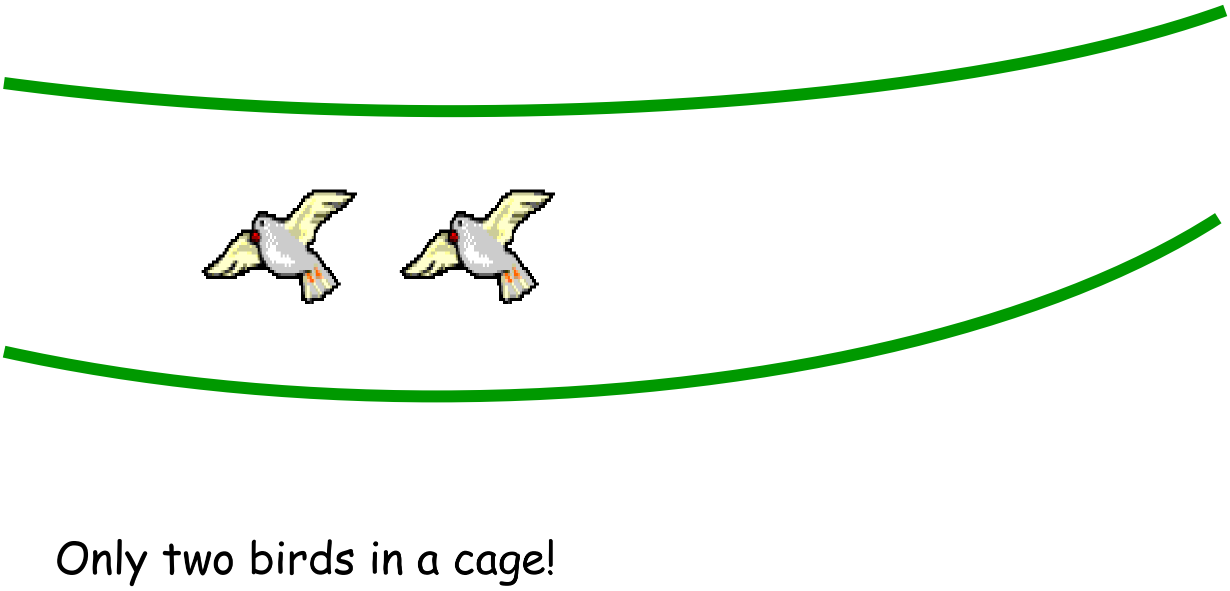


Figure E. 1. e

Slide 8

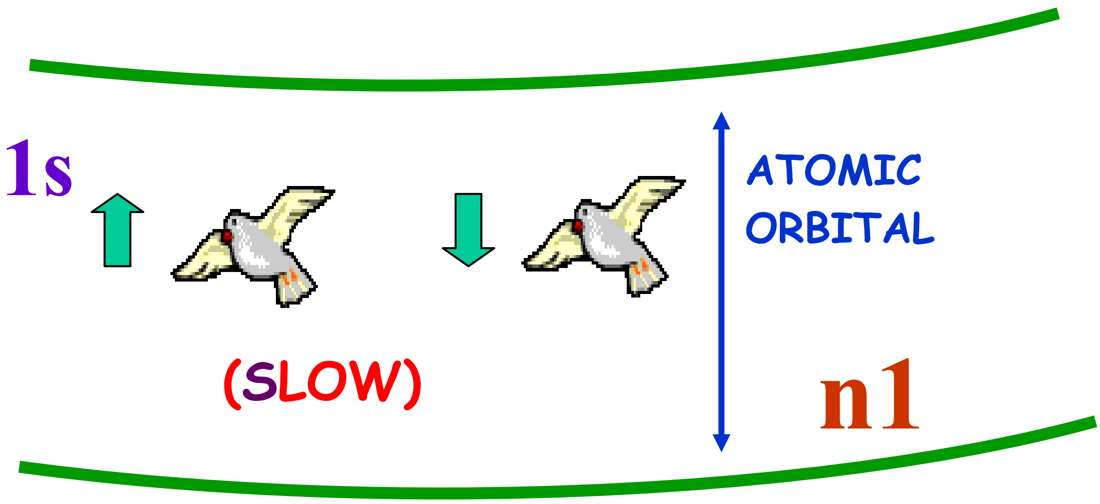


Figure E. 1. f

Slide 9

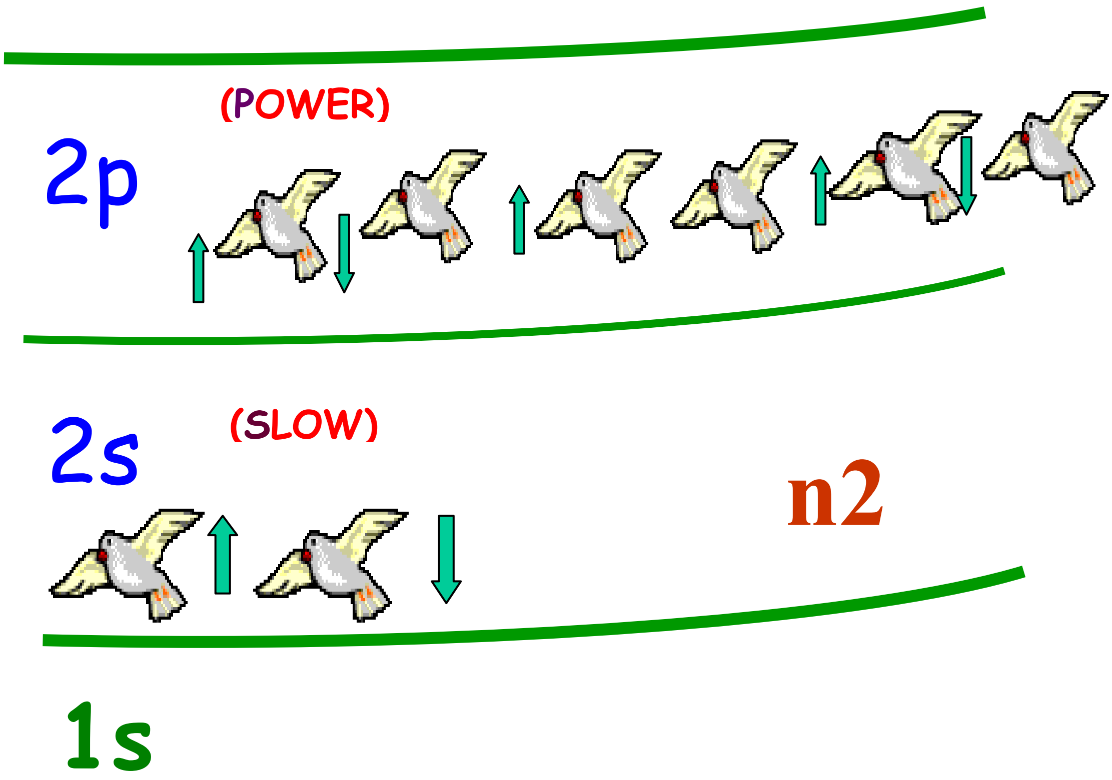


Figure E 1 g.

Slide 10

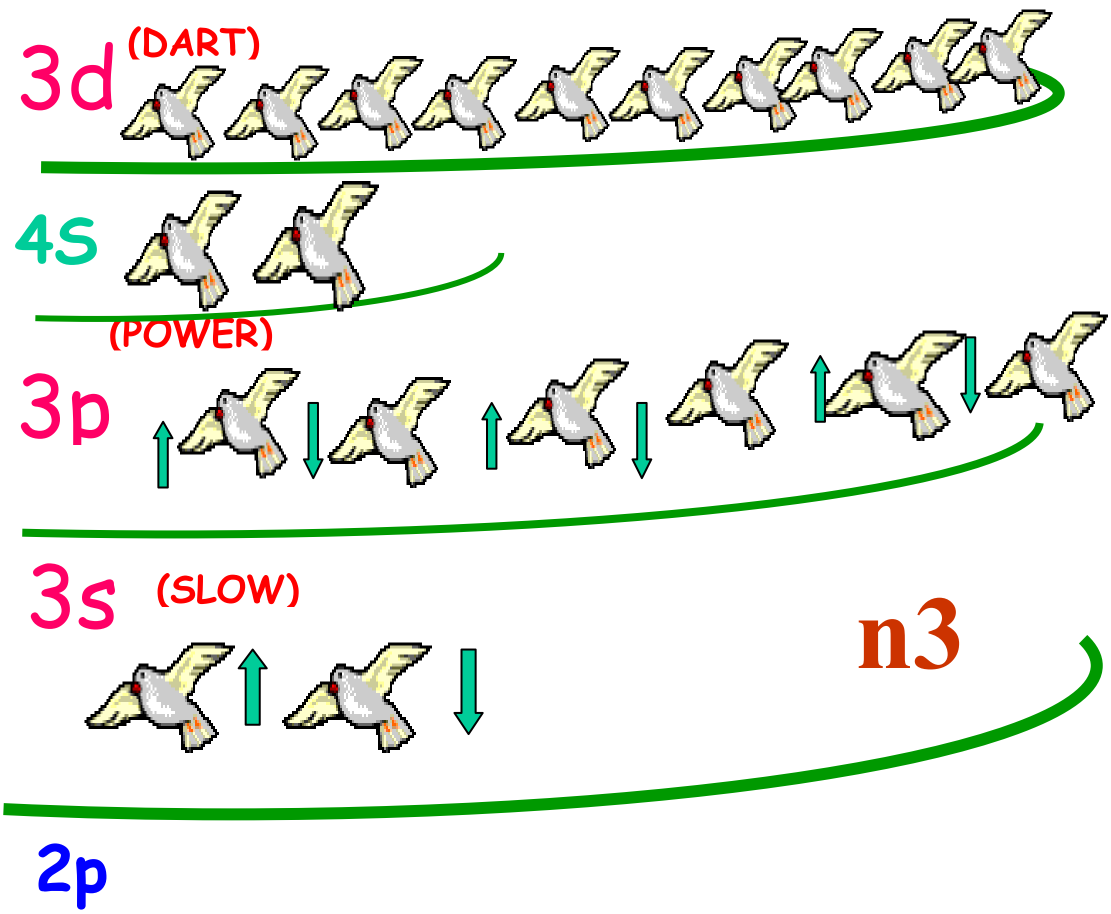


Figure E 1 h.

Slide 11

Analog mapping

Guess the targets for the following analogs:

Analog	Target
Birds	Electrons
Branch	
Cage	
Spinning position	
Slow level	
Power level	
Dart level	
Fastest level	
A pair of birds	

Please refer to E 9 & 10 for the Power Point presentation

APPENDIX E. 2

Revised Analogy

Quantum Mechanical Model - Electron Configuration

1. Added to include HUND'S RULE

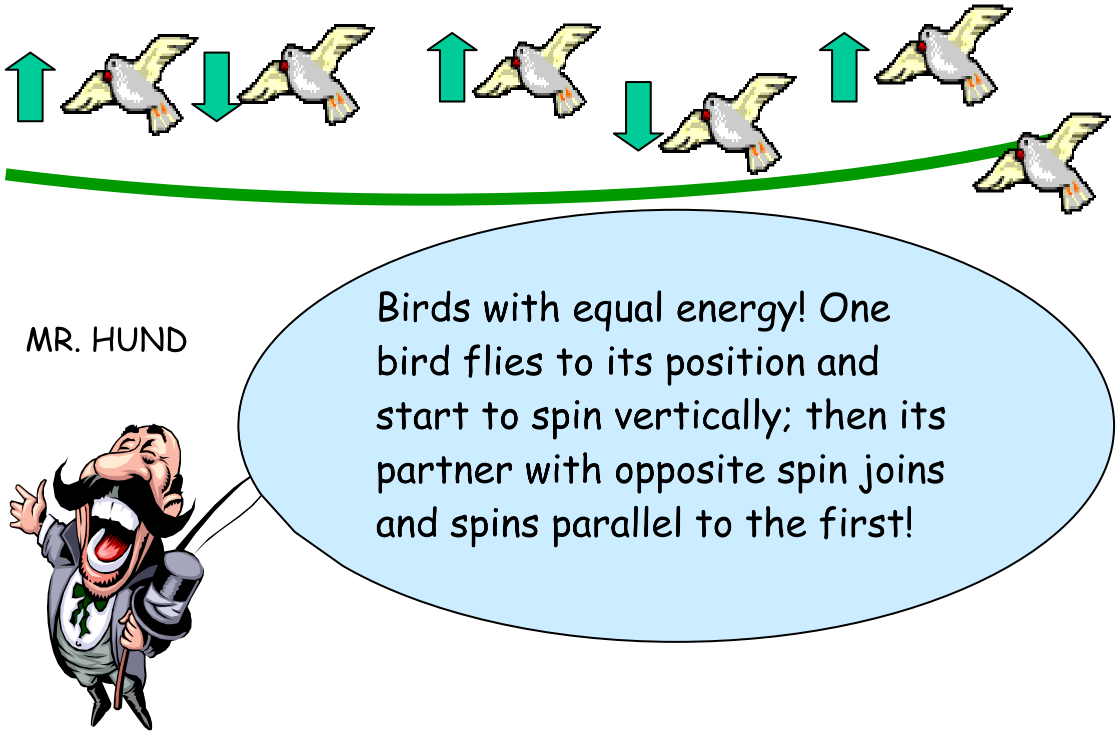


Figure E 2 a

2. Added to include AUBAU PRINCIPLE

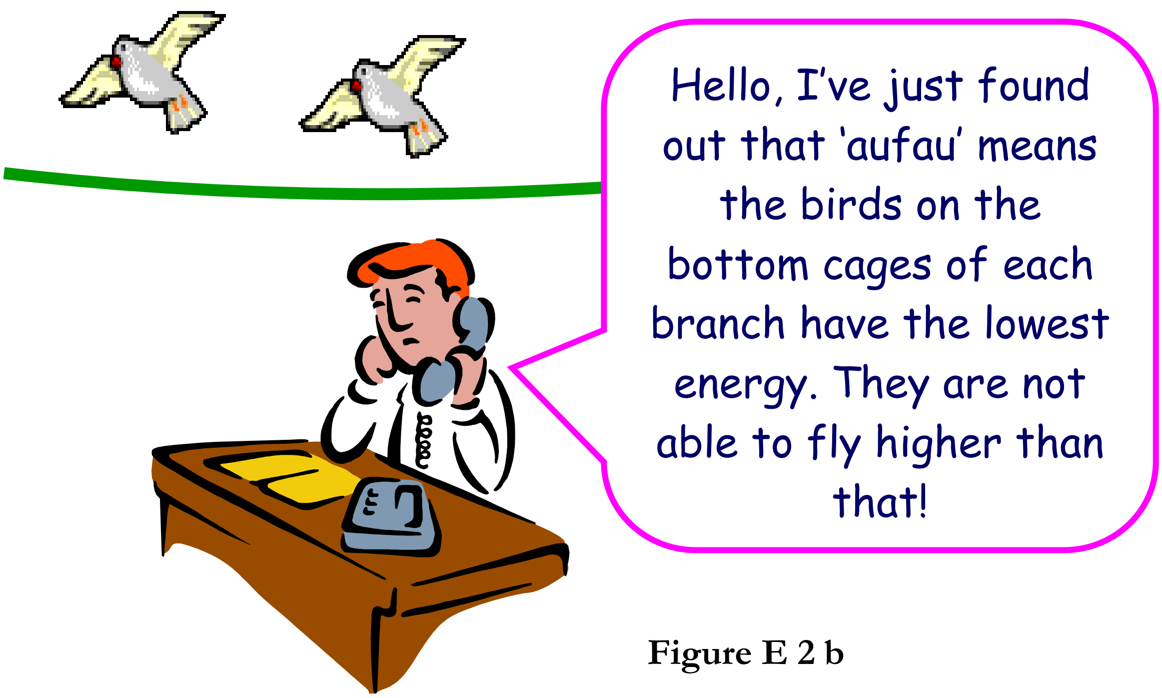


Figure E 2 b

3. Added to include PAULI'S EXCLUSION PRINCIPLE

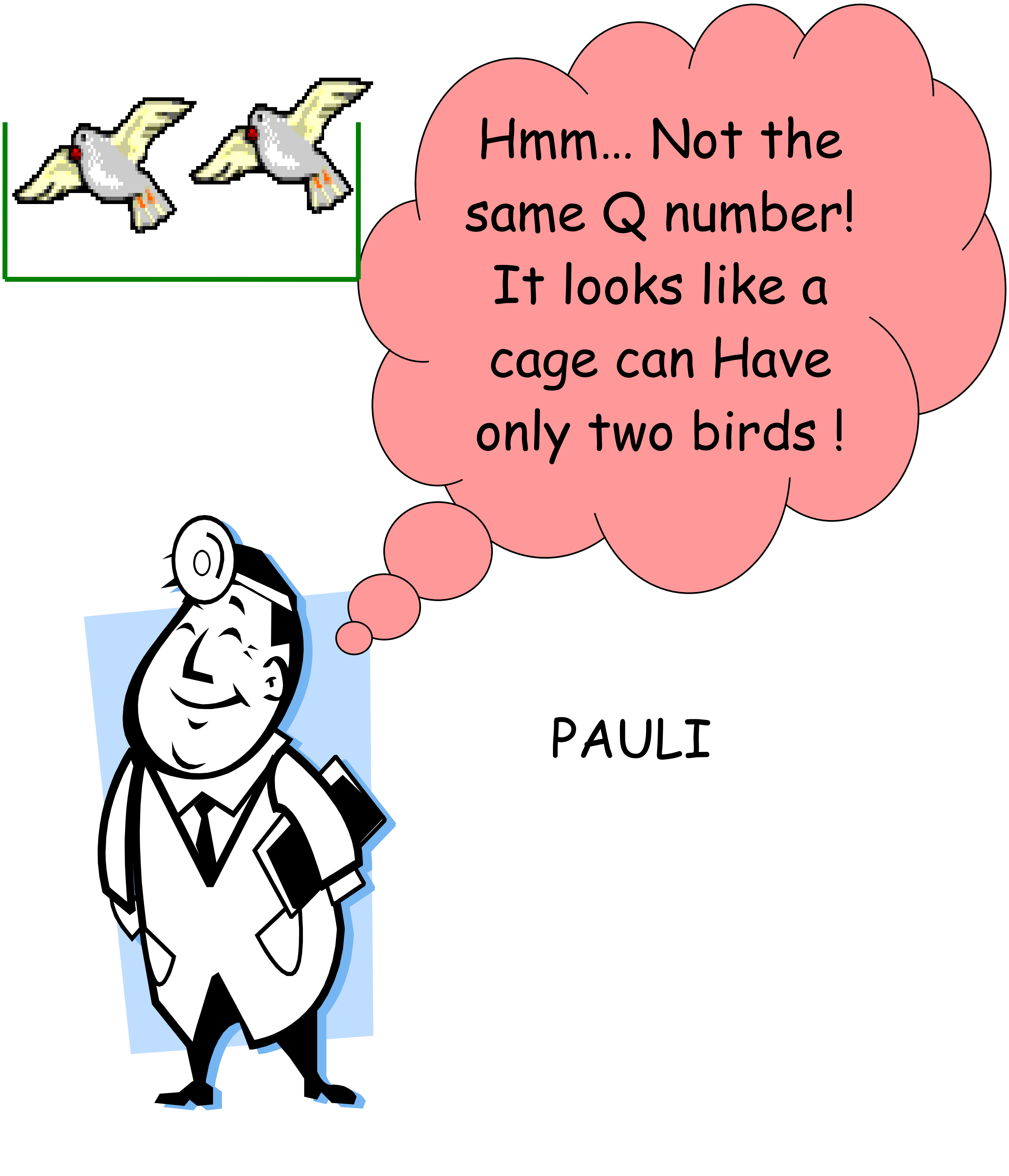


Figure E 2 c

4. Added to show the approximate positions of the electrons

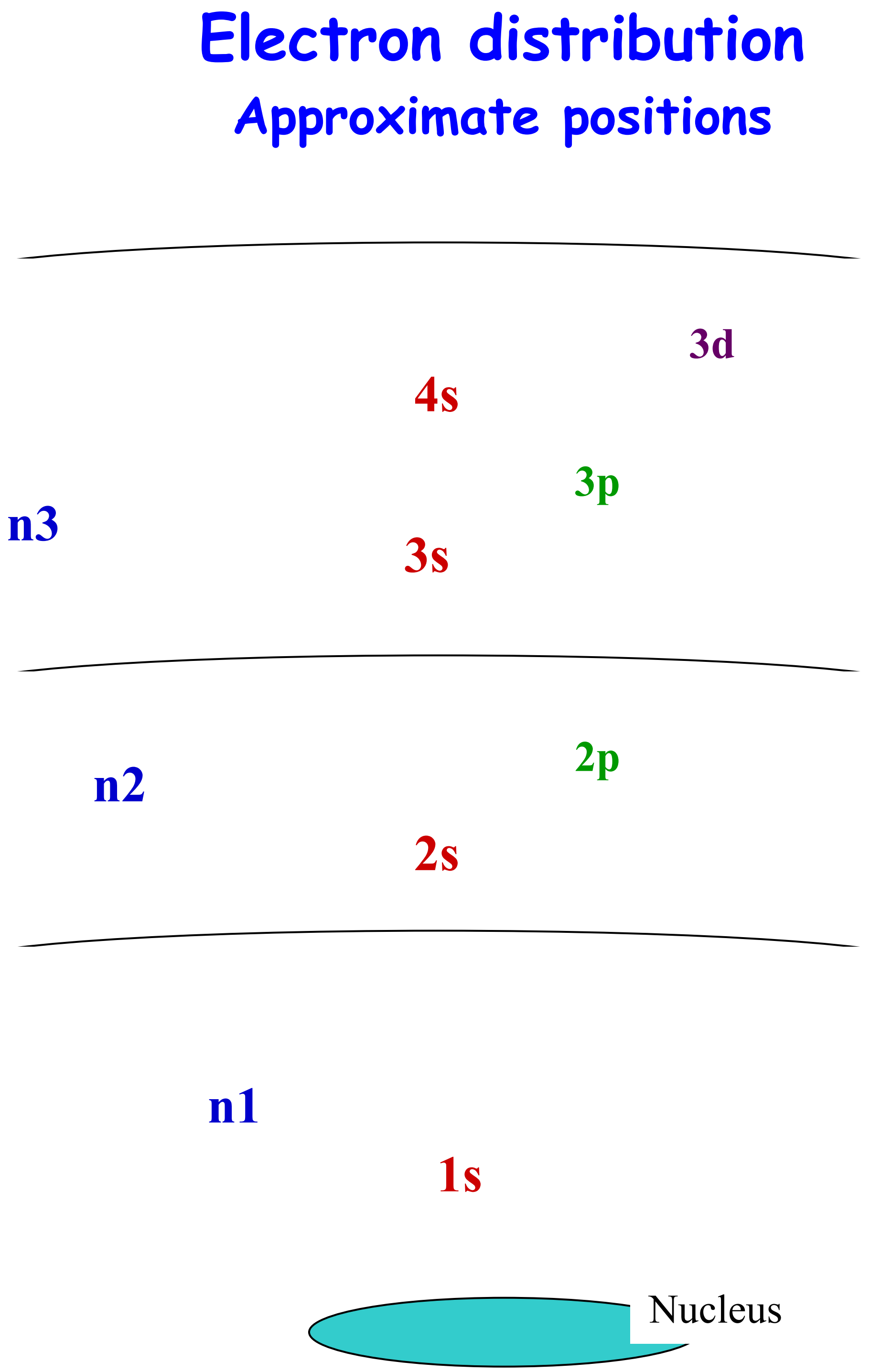


Figure E 2. d

(Note: See E 9 & 10 Power Point Presentation as it was shown to the students)

APPENDIX E. 3

The FAR Guide to teach the analogy for Electron Configuration

Focus

Concept	Is it difficult, unfamiliar, or abstract?	The chosen concept, 'Electron Configuration' is difficult, unfamiliar and abstract.
	Students	The students have very limited knowledge of the concept and they were never taught this concept earlier.
	Analog	The students are familiar with the chosen analog, which is a power point presentation of a tree with lateral branches, where birds take up positions .at various levels.

Action

Likes	Discuss the features of analog and the science concept.Draw similarities between them.	The tree is represents an atom and the lateral branches are orbits showing the various energy levels and orbitals. Each branch is named starting with the first letter of the corresponding orbital. For e.g. 's' orbital corresponds to the 'Slow' branch, 'p' to 'Power' branch and 'd' to 'Dart' branch.
Unlikes	Discuss where the analog is unlike the science concept.	The analogy resembles the atom and electron configuration largely. There will be a discussion in the class and the students will be encouraged to raise the dissimilarities, discuss and make conclusions.

Similarities mapped out in detail

ANALOG	ANALOG -FEATURES	TARGET
The branches	The lines of different colours, specific for a particular branch. e.g. 1^{st} branch is brown in colour, 2^{nd} is purple and so on	The quantum number n1, n2 and so on
Cage	A blue box housing a pair of birds inside	An orbital with a pair of electrons
Slow branch	The lowest lateral branch of a main branch called 'slow' (1s/2s/3s,etc)	's' level
Power branch	The branch above the lowest branch of a main branch called 'power' (2p/3p, etc)	'p' level
Dart branch	The branch above the 'power' branch called 'dart' (4d/5d, etc)	'd' level
Fastest branch	The highest lateral branch of a main branch called 'fastest' (4f, 5f, etc)	'f' level
Bird	Flapping its wings inside the cage.	Electron spinning in an orbital
A pair of birds	Two birds flapping its wings inside the cage.	Two electrons with lowest energy at lowest orbital (Aufbau)
Single bird in a cage	Flapping its wings inside the cage.	Electron with same energy and opposite spin (Hund's)
Presumption that the birds spin vertically in opposite direction	Two birds flapping its wings inside the cage.	Two electrons with different Quantum number together (Pauli's exclusion principle)

Reflection

Conclusions	Was the analog clear and useful or confusing?	The students were quite excited about the power point presentation of the imaginary computer game. The discussion revealed that they were able to understand better with the analogy. Did they mean it? It is a very difficult concept to grasp. One student wanted a copy of the animation and he said that he 'loved' it! Will it help them to answer the application questions? The scientists will be subtly included in the presentation next time to help remember the rules.
Improvement	Refocus light of outcomes	The analog will be refocused in the light of the above outcomes.

APPENDIX E. 4

Two-*Tier Diagnostic Instrument on the understanding of Electrons in Atoms*

Procedure and Instrumentation based on the procedure described by Treagust (1986).

What do you know about electrons in atoms?

The following pages contain 11 questions about electrons in atoms. Each question has two parts: A Multiple Choice Response followed by a Multiple Choice Reason. You are asked to make **one choice** from both the Multiple Choice Response section and **one choice** from the Multiple Choice Reason section for each question.

If you have another reason for your answer, write in the space provided as well as making the choice letter in the reason box.

Answer all questions on the separate answer sheet

1. Read each question carefully.

2. Take time to calculate and consider your answer.

3. Record your answer in the correct box on the answer sheet.

e.g. Q.5 $\boxed{2}$ Reason $\boxed{}$

4. Read the set of possible reasons for your answer.

5. Carefully select a reason, which best matches your thinking when you work out the answer.

6. Record your answer in the correct reason box on the Answer sheet.

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{C}$

7. If you change your mind about an answer, cross out the old answer and add the new choice.

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{\cancel{C}}$ A

8. If you wish to provide your own reason for the question, write your reason on the sheet in the space provided (d).

e.g. Q. 5 $\boxed{2}$ Reason $\boxed{}$ ____________________

____

Don't forget to record your name and other details on your Answer sheet.

What do you know about electrons in atoms?

Question 1. Can the positively charged protons pull the negative electrons towards the nucleus and cause a collapse of the atom?

1. Yes
2. No
3. I am not sure
4. **Any other or your own answer:** ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s were:
a) Oppositely charged particles attract each other.
b) The electrons have fixed energy to keep them at their energy levels.
c) When the proton number is greater, the electrons would be drawn into the positive nucleus.
4. Any other or your own: ______________________________

Question 2. What is meant by 'energy level'?

1. The strength of an electron
2. It is the power with which the electron is pulling itself away from the nucleus
3. The region around the nucleus where an electron is likely to be moving
4. **Any other or your own answer:** ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s were:
a) The possibility of finding an electron is in this area
b) The energy is picked up by an electron in this region
c) Energy level shows the speed of an atom in its path
d) **Any other <u>reason</u> for your answer**: ______________________________

Question 3. What is meant by a quantum of energy?
Your answer:
1) The energy has a unit just like metre for length and kilogram for mass so that we know its quantity
2) We can analyse an atom quantitatively
3) It is the amount of energy needed to move an electron from the present to a higher level.
4) Any other or your own answer: ______________________________

The reason for choosing the above answer: When I wrote this answer, my thought/s was/were:
a) We need to know the quantity of energy in an electron
b) The energy of an electron can be analysed
c) An electron can't move to a higher level without energy
d) Any other reason for your answer: ______________________________

Question 4. What is an atomic orbital?
Your answer:
1. A region where there is a high probability of finding an electron
2. A region where there many concentric circles in an atom
3. A region where the electrons orbitate in clouds
4 **Any other or your own answer:** ______________________________

The reason for choosing the above answer:
When I wrote this answer, my thought/s were:
a) The quantum model suggests that an atomic orbital is where an atom is placed
b) The quantum model suggests that an atomic orbital is a dense, negatively charged cloud having electron/s
c) The quantum model suggests that an atomic orbital is highest energy point in an atom
d) **Any other reason for your answer:** ______________________________

Question 5. What is meant by 'electron configuration'?
Your answer:
1) The number of electrons in an atom
2) The arrangement of electrons in an atom
3) It is the way an electron is figured out around the nucleus
4) **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Each atom has a certain number of electrons
b) This is a rule to calculate the number of electrons an atom
c) The arrangement of electrons is unique in atoms of each element
d) **Any other reason for your answer**: ____

Question 6. Which of the orbitals has electrons with the lowest energy?
Your answer:
1. x orbital
2. p orbital
3. s orbital
4. **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) p orbital is away from the nucleus and has electrons with the lowest energy
b) s orbital is closer to the nucleus and has electrons with the lowest energy
c) x orbital has all the weak electrons with the lowest energy
d) **Any other reason for your answer**: ____

Question 7. What is the criterion that governs the filling of atomic orbitals by electrons, according to Aufbau's principle?
1) Electrons with the highest energy enter the orbitals of lowest energy at first
2) Electrons with the lowest enter the orbitals of lowest energy at first
3) Electrons with the lowest energy enter the orbitals of highest energy at first
4) **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Electrons with the highest energy shoots out to occupy the s orbital
b) Electrons with the lowest energy enters the s orbital at first
c) Electrons entering the s orbital has nothing to do with the energy level
d) **Any other reason for your answer**: ____

Question 8. What is the maximum number and nature of electrons that can occupy an orbital?
1. A pair with parallel spin
2. A pair with opposite spin
3. A pair with horizontal spin
4. **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:
a) Spin in the same direction is likely to keep the electrons together
b) Spin in the opposite direction is likely to keep the electrons together
c) Horizontal spin is more stable and this is likely to keep the electrons together
d) **Any other reason for your answer**: ____

Question 9. When does a single electron occupy an orbital?

1) When there is no second electron having higher energy level and opposite spin
2) When there is no second electron having higher energy level and same spin
3) When there is no second electron having the same energy level and opposite spin
4) **Any other or your own answer:**____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:

a) Hund's rule governs the above condition
b) Aufbau's principle governs the above condition
c) The Pauli exclusion principle governs the above condition
d) **Any other reason for your answer**: ____

Question 10. What do modern physicists say about the shape of an atom?

1. Atoms have spherical shape
2. Atoms have dumb bell shape
3. Atoms have no definite shape

4) **Any other or your own answer:**____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:

a) There are circular orbits around the nucleus of an atom
b) There are dumb bell shaped electron clouds around the nucleus of an atom
c) The position of an electron is a probability and this determines the shape of the atom
d) **Any other reason for your answer**: ____

Question 11. What do modern physicists say about the path of an electron?

1) The electrons have no precise orbits
2) The electrons have precise orbits
3) The electrons are just like planets around the sun
4) **Any other or your own answer:** ____

The reason for choosing the above answer:
When I wrote this answer, my thought/s was/were:

a) The electrons need a path to move without colliding with each other
b The fixed energy level of an electron keeps it moving along a certain path around the nucleus
c) The path taken by an electron is specific for a particular atomic radius
d) Any other reason for your answer: ____

ANSWER SHEET

Quantum Mechanical Model

What do you know about electrons in atoms?

Name ______________________________ Class: ______________________

Date: ______________ Male: __________ Female: _________ Age: _________________

Q. 1 Answer	☐	Q.1 Reason	☐
Q. 2 Answer	☐	Q.2 Reason	☐
Q. 3 Answer	☐	Q.3 Reason	☐
Q. 4 Answer	☐	Q.4 Reason	☐
Q. 5 Answer	☐	Q.5 Reason	☐
Q. 6 Answer	☐	Q.6 Reason	☐
Q. 7 Answer	☐	Q.7 Reason	☐
Q. 8 Answer	☐	Q.8 Reason	☐
Q. 9 Answer	☐	Q.9 Reason	☐
Q. 10 Answer	☐	Q.10 Reason	☐
Q. 11 Answer	☐	Q. 11 Reason	☐

What do you know about electrons in atoms?

ANSWER SHEET

Name ______________________________ Class: ______________________

Date: ______________ Male: __________ Female: _________ Age: ________________

Q. 1 Answer	2	Q.1 Reason	b
Q. 2 Answer	3	Q.2 Reason	a
Q. 3 Answer	3	Q.3 Reason	c
Q. 4 Answer	1	Q.4 Reason	b
Q. 5 Answer	2	Q.5 Reason	c
Q. 6 Answer	3	Q.6 Reason	b
Q. 7 Answer	2	Q.7 Reason	b
Q. 8 Answer	2	Q.8 Reason	b
Q. 9 Answer	3	Q.9 Reason	a
Q. 10 Answer	3	Q.10 Reason	c
Q. 11 Answer	1	Q.10 Reason	b

APPENDIX E. 5

7. 2. 4. Analysis of Individual Responses

Q. No. 1 Can the positively charged protons pull the negative electrons towards the nucleus and cause a collapse of the atom?

Correct Answer: No.

There was an increase of 22.8% after the presentation of the analogy and the posttest average was 77%. This indicates that the students became aware of the 'balancing power' of electrons.

Alternate Conception: *Yes.*

Though there was a decrease of 16.2% in the posttest average, this alternate conception was still held by 18% of the students. This was clarified during the posttest review.

3. I am not sure. None chose this answer in the posttest.

Correct reason: b. *The electrons have fixed energy to keep them at their energy levels*

The posttest average showed an increase of 22.7%, indicating that the analogy helped in understanding the concept. 73% of the students chose this reason.

Alternate conception: *Oppositely charged particles attract each other.*

This alternate conception was held by 18% after the presentation of the analogy and this was clarified during the posttest review.

Misconception: *When the proton number is greater, the electrons would be drawn into the positive nucleus.* This was held by a negligible number of students and was clarified later.

Q. No. 2 What is meant by 'energy level'?

Correct Answer: 3. **The region around the nucleus where an electron is likely to be moving.**

The posttest score increased by 18% and 77% of the cohort chose this answer

The strength of an electron .1. No one chose this answer after the analogy was presented.

Alternate conception: *It is the power with which the electron is pulling itself away from the nucleus.*

This was chosen by 23% of the students, who assign the concept of 'energy level' to the pulling power of electrons to move away from the nucleus.

Correct reason: a. The possibility of finding an electron is in this area.

The same average of 41% was maintained in both the tests. Further clarification was needed regarding the energy level and it was done during the posttest review.

Alternate conception: *b. The energy is picked up by an electron in this region.*

This alternate conception was held by 27% of the students, which was clarified later.

Alternate conception: *Energy level shows the speed of an atom in its path.*

Unfortunately, 32% of the students believed and this was clarified later.

Table 7. 1 Continued. . .	Concept - Quantum Mechanical Model of an Atom	Average %		
		Pretest	Posttest	Increase/ Decrease
Q.No.3	**What is meant by a quantum of energy?**			
Correct Answer	**3. It is the amount of energy needed to move an electron from the present to a higher level.**	77.3	86.4	9.1
Misconception	1.The energy has a unit just like metre for length and kilogram for mass so that we know its quantity.	4.55	4.55	0
Misconception	2.We can analyse an atom quantitatively.	18.2	9.09	-9.11
Correct Reason	**c. An electron can't move to a higher level without energy.**	68.2	72.7	4.5
Misconception	a. We need to know the quantity of energy in an electron.	13.6	9.09	-4.51
Misconception	b. The energy of an electron can be analysed.	18.2	18.2	0
Q.No.4	**What is an atomic orbital?**			
Correct Answer	**1 A region where there is a high probability of finding an electron.**	27.3	36.4	9.1
Misconception	2. A region where there many concentric circles in an atom.	22.7	4.55	-18.15
Misconception	3. A region where the electrons orbitate in clouds.	50	59	9
Correct Reason	**b. The quantum model suggests that an atomic orbital is a dense, negatively charged cloud having electron/s.**	54.5	59	4.5
Misconception	a. The quantum model suggests that an atomic orbital is where an atom is placed.	18.2	27.3	9.1
Misconception	c The quantum model suggests that an atomic orbital is highest energy point in an atom.	27.3	13.6	-13.7
Q.No.5	**What is meant by 'electron configuration'?**			
Correct Answer	**2. The arrangement of electrons in an atom.**	63.6	68.2	4.6
Misconception	1. The number of electrons in an atom.	9.09	13.6	4.51
Misconception	3. It is the way an electron is figured out around the nucleus.	27.3	18.2	-9.1
Correct Reason	**c. The arrangement of electrons is unique in atoms of each element**	59.09	63.64	4.55
Misconception	a. Each atom has a certain number of electrons	0	9.09	9.09
	b. This is a rule to calculate the number of electrons an atom	9.09	36.36	27.27
	d. Students' own	4.55	0	-4.55

Q. No. 3 What is meant by a quantum of energy?

Correct Answer: 3. It is the amount of energy needed to move an electron from the present to a higher level

This answer was chosen by 86% of the students and showed an increase of 9% after the analogy was presented.

Misconception: *The energy has a unit just like metre for length and kilogram for mass so that we know its quantity.*

The misconception was held by very few students and was clarified later.

Misconception: *We can analyse an atom quantitatively.*

A few of the students (9%) held the misconception that this statement refers to the fact that we can quantify an atom.

Correct Reason: c. An electron can't move to a higher level without energy

This reason was chosen by 73% of the cohort in the posttest, about 5% more than the pretest.

Misconception: *We need to know the quantity of energy in an electron.*

Though there was a decrease of about 5% in this misconception after the presentation of the analogy, 9% sill held the view.

Alternate conception: *The energy of an electron can be analysed.*

b. All the 18% of the students, changed their alternate conception on quantum energy completely in the posttest.

Q. No. 4 What is an atomic orbital?

Correct Answer: **1 A region where there is a high probability of finding an electron**

The above answer was chosen by 36% of the cohort in the posttest, though the average increased by 9% from the pretest.

Misconception: *A region where there many concentric circles in an atom.*

There was a decrease of 18% average in the posttest and only 5% held this conception after the presentation of the analogy though this is what they are taught at primary level.

Alternate conception: *A region where the electrons orbitate in clouds.*

As many as 59% held this conception indicating that they were unsure even after the presentation of the analogy and hence, matched the words, 'orbit' and 'orbitate'.

Correct Reason: b. The quantum model suggests that an atomic orbital is a dense, negatively charged cloud having electron/s

The correct reason was chosen by 59% of the cohort, an increase of 5% from the pretest, which indicates that the analogy was helpful to a certain extent.

Alternate misconception: *The quantum model suggests that an atomic orbital is where an atom is placed.*

This alternate misconception was held by 27% of the students, even after the presentation of the analogy and was taken up for discussion and clarified.

Alternate misconception: *The quantum model suggests that an atomic orbital is highest energy point in an atom.*

Though there was a decrease of 14%, this alternate conception was held by 14% in the posttest, which was clarified during the posttest review.

Q. No. 5 What is meant by 'electron configuration'?

Correct Answer: 2. *The arrangement of electrons in an atom*

As many as 68% of the students believed that electron configuration meant that the manner of arrangement of electrons in an atom. The posttest average showed an increase of 5% from the pretest.

Alternate conception: *The number of electrons in an atom.*

This alternate conception was held by 14% of the students even after the presentation of the analogy. Unfortunately, this showed an increase of 5% in the posttest average, indicating that this needed clarification and this was done during the posttest review.

Alternate conception: *It is the way an electron is figured out around the nucleus.*

A few students looked at the statement superficially and interpreted the literal meaning. The majority of the students in the class, who took part in the study, were not native speakers of English. 18% still held this view though the posttest average showed a decrease of 9% after the presentation of the analogy.

Correct Reason: c. The arrangement of electrons is unique in atoms of each element.

This reason was chosen by 64% of the students, which was an increase of 5% from the pretest. This was not directly related to the analogy, but during the explanation this was brought out to reinforce student-understanding.

Misconception: *Each atom has a certain number of electrons*

a. Though the statement is correct this answer does not relate to the question and is clearly a misconception, which is held by 9% of the students.

Alternate conception: *This is a rule to calculate the number of electrons an atom.*

b. Unfortunately, 36% of the students held this alternate conception even after the presentation of the analogy and had to be discussed and clarified later.

Table 7. 1 Continued. . .	Concept - Quantum Mechanical Model of an Atom	Average %		
		Pretest	**Posttest**	**Increase/ Decrease**
Q.No.6	**Which of the orbitals has electrons with the lowest energy?**			
Correct Answer	**3. s orbital**	72.7	86.4	13.7
Misconception	1. x orbital	13.6	9.09	-4.51
Misconception	2. p orbital	9.09	4.55	-4.54
Misconception	4. Students' own	4.55	0	-4.55
Correct Reason	**b. s orbital is closer to the nucleus and has electrons with the lowest energy.**	68.2	81.8	13.6
Misconception	a. p orbital is away from the nucleus and has electrons with the lowest energy.	4.55	4.55	0
Alternate conception	c. x orbital has all the weak electrons with the lowest energy.	22.7	9.09	-13.61
Misconception	d. Students' own.	4.55	4.55	0
Q.No.7	**What is the criterion that governs the filling of atomic orbitals by electrons, according to Aufbau's principle?**			
Correct Answer	2. Electrons with the lowest energy enter the orbitals of lowest energy at first.	45.5	68.2	22.7
Alternate conception	1. Electrons with the highest energy enter the orbitals of lowest energy at first.	31.8	13.6	-18.2
Alternate conception	3. Electrons with the lowest energy enter the orbitals of highest energy at first.	22.7	18.2	-4.5
Correct Reason	**b. Electrons with the lowest energy enters the s orbital at first.**	45.5	68.2	22.7
Alternate conception	a. Electrons with the highest energy shoots out to occupy the s orbital.	27.3	18.2	-9.1
Misconception	c. Electrons entering the s orbital has nothing to do with the energy level.	4.55	9.09	4.54
Q. No. 8	**What is the maximum number and nature of electrons that can occupy an orbital?**			
Correct Answer	**2 A pair with opposite spin.**	68.2	59.1	-9.1
Alternate conception	1. A pair with parallel spin.	13.6	31.2	17.6
Misconception	3. A pair with horizontal spin.	13.6	9.09	-4.51
Misconception	4. Students' own.	4.55	4.55	0
Correct Reason	**b. Spin in the opposite direction is likely to keep the electrons together.**	68.2	68.2	0
Alternate conception	a. Spin in the same direction is likely to keep the electrons together.	13.6	22.7	9.1
Misconception	c. Horizontal spin is more stable and this is likely to keep the electrons together.	9.09	9.09	0
Misconception	d. Students' own.	9.09	0	-9.09

Q. No. 6 Which of the orbitals has electrons with the lowest energy?

Correct Answer: 3. s orbital

The above correct answer was chosen by 86% of the students in the posttest, which showed an increase of 14% from the pretest.

Misconception: *x orbital*

This misconception was held by 9% of the students who guessed the answer.

Misconception: *p orbital*

The posttest average decreased by 5%; but still there were 5% of the students, who held this notion. This was clarified during the posttest review.

Correct Reason: b. *s orbital is closer to the nucleus and has electrons with the lowest energy.*

The above correct reason was chosen by 82% after the presentation of the analogy and the posttest average showed an increase of 14% from the pretest.

Misconception: *p orbital is away from the nucleus and has electrons with the lowest energy.*

This misconception was held by 5% and was clarified later.

Misconception: *x orbital has all the weak electrons with the lowest energy.*

This imaginary answer was chosen by 9% of the students in the posttest, though there was a decrease of 14% from the pretest. This misconception was taken up for discussion and clarified with the other misconceptions during the posttest review.

Q.No.7 What is the criterion that governs the filling of atomic orbitals by electrons, according to Aufbau's principle?

Correct Answer: 2. Electrons with the lowest energy enter the orbitals of lowest energy at first

The posttest average was 68% showing an increase of 23% after the presentation of the analogy. This indicates that the students were benefited from the analogy.

Alternate conception: *Electrons with the highest energy enter the orbitals of lowest energy at first.*

Though the posttest average showed a decrease of 18%, there were still 14% of the students, who believed in the above statement.

Alternate conception*: Electrons with the lowest energy enter the orbitals of highest energy at first.*

The posttest average showed a decrease of 5%, this alternate conception, but still was held by 18% of the students. The above two alternate conceptions were clarified during the posttest review.

Correct Reason: b. *Electrons with the lowest energy enters the s orbital at first.*

There was an increase of 23% in the posttest average from the pretest, showing that the presented analogy assisted in better understanding of the concept.

Alternate conception: *Electrons with the highest energy shoots out to occupy the s orbital.*

The above alternate conception was held by 18% and was clarified later.

Alternate conception: *Electrons entering the s orbital has nothing to do with the energy level.*

The misconception that 'electrons entering the s orbital have nothing to do with the energy level' showed a decrease of 5% but was still held by 9% of the students and was clarified during the posttest review.

Q. No. 8 What is the maximum number and nature of electrons that can occupy an orbital?

Correct Answer: 2 *A pair with opposite spin.*

Unfortunately there was a decrease of 9% from the pretest and this brought down the posttest average from 68% to 59%. Lack of focus and effort to retain in memory caused this problem and was clarified later.

Alternate conception: *A pair with parallel spin.*

1. This distractor had a part of the correct answer, but not accepted as the students were asked to choose the best relevant answer for the question given. This alternate conception was held by 31% of the students, an increase of 18% after watching the animation of birds, which represented the spin in the given in the analogy. The revised animation and discussion cleared this alternate conception.

Alternate conception: *A pair with horizontal spin.*

This misconception was held by 9%, though decreased by 5% in the posttest average. The discussion after the revised animation presented clarified this point.

Correct Reason: *b. Spin in the opposite direction is likely to keep the electrons together.*

The above reason was chosen by 68% of the students in the pre and posttest and it seemed that the analogy did little to improve the understanding of this concept.

a. This alternate conception was held by 23% as shown by the posttest average, even after the presentation of the concept. Unfortunately the average showed an increase of 9% from the pretest. This was clarified during the posttest review.

c. This misconception was held by 9% of the students and was clarified later.

Table 7. 1 Continued. . .	**Concept - Quantum Mechanical Model of an Atom**	**Average %**		
		Pretest	**Posttest**	**Increase/ Decrease**
Q.No.9	**When does a single electron occupy an orbital?**			
Correct Answer	**3. When there is no second electron having the same energy level and opposite spin**	63.64	54.55	-9.09
Misconception	1. When there is no second electron having higher energy level and opposite spin	27.27	18.18	-9.09
Misconception	2. When there is no second electron having higher energy level and same spin	5.66	27.27	21.61
Misconception	4.Students' own	4.55	0	-4.55
Correct Reason	**a. Hund's rule governs the above condition**	22.7	27.3	4.6
Misconception	b. Aufbau's principle governs the above condition	31.8	45.5	13.7
Misconception	c. The Pauli exclusion principle governs the above condition	36.4	27.3	-9.1
Misconception	d. Students' own	9.09	0	-9.09
Q. No. 10	**What do modern physicists say about the shape of an atom?**			
Correct Answer	3. Atoms have no definite shape	59.1	50	-9.1
Misconception	1. Atoms have spherical shape	36.4	36.4	0
Misconception	2. Atoms have dumb bell shape	4.55	13.6	9.05
Correct Reason	**c The position of an electron is a probability and this determines the shape of the atom**	59.1	63.6	4.5
Misconception	a. There are circular orbits around the nucleus of an atom	22.7	18.2	-4.5
Misconception	b. There are dumb bell shaped electron clouds around the nucleus of an atom	18.2	18.2	0
Question. 11	**What do modern physicists say about the path of an electron?**			
Correct Answer	**1. The electrons have no precise orbits**	18.2	31.8	13.6
Alternate conception	2.The electrons have precise orbits	18.2	13.6	-4.6
Alternate conception	3. The electrons are just like planets around the sun	50	40.9	-9.1
Alternate conception n	4.Students' own	13.6	13.6	0
Correct Reason	**b. The fixed energy level of an electron keeps it moving along a certain path around the nucleus**	27.3	45.5	18.2
Alternate conception	a. The electrons need a path to move without colliding with each other	27.3	27.3	0
Alternate conception	c. The path taken by an electron is specific for a particular atomic radius	31.8	13.6	-18.2
Alternate conception	d. Students' own	13.6	13.6	0

Q. No. 9 When does a single electron occupy an orbital?

Correct Answer: **3. When there is no second electron having the same energy level and opposite spin**

This was not shown in the animation, but the students were expected to exercise their higher order thinking skills to arrive at this answer. There was a decrease of 9% in the posttest average. 56% of the students held this correct conception.

Alternate conception: *When there is no second electron having higher energy level and opposite spin.*

The students seemed to have guessed the answer since they were not sure of the answer. There was an increase of 22% in the posttest average.

Alternate conception: *When there is no second electron having higher energy level and same spin.*

Though the posttest average for this answer showed a decrease of 22%, this alternate conception was held by 27% of the students.

The above two alternate conceptions were clarified during the posttest review.

Correct Reason: a. Hund's rule governs the above condition

Only 27% of the students knew the correct reason, despite the 5% increase in the posttest average. This gave me the idea of revising the analogy by adding the names of the scientists to the analogy. The students felt that this would help them to remember the names of the scientists and the associated concepts.

Alternate conceptions: *Aufbau's principle governs the above condition and the Pauli Exclusion Principle governs the above condition.*

The above two alternate conceptions emerged as result of the students' guess work. It is obvious that they were not sure of the correct reason. The 'Reflection' after the analysis of the posttest score induced me to add a few slides to the Power Point presentation, which included the associated scientists and their contributions. The posttest average showed 46% and 27% respectively. The reason 'b' showed an increase of 14% from the pretest and 'c' showed a decrease of 9%. Both the alternate conceptions clarified during the posttest review.

Q. No. 10 What do modern physicists say about the shape of an atom?

Correct Answer: 3. Atoms have no definite shape

The correct answer was chosen by 50% of the cohort and this showed a decrease of 9% from the pretest unfortunately.

Alternate conception: Atoms have dumb bell shape

This incorrect perception was held by 14% of the students and was clarified for them during the posttest review.

Alternate conception: *Atoms have spherical shape.*

This conception was held by 36%, who remembered the primary teaching of concentric circles of orbits in an atom. The analogy did not have any direct bearing on this concept. This is an example of how misconceptions could creep in. A teacher must caution students that changes in scientific perceptions are inevitable and they would be dealing with the latest at higher levels; this might enable them to accommodate changes readily.

Correct Reason: c The position of an electron is a probability and this determines the shape of the atom

The posttest average was 64%, an increase of 6% from the pretest.

The alternate conceptions: *There are circular orbits around the nucleus of an atom and There are circular orbits around the nucleus of an atom.*

The above alternate conceptions were held by 18% of the cohort. This was clarified and further reinforced during the presentation of the revised analogy.

Question. 11 What do modern physicists say about the path of an electron?

Correct Answer: 1. *The electrons have no precise orbits*

The posttest average was 32%, despite the increase of 14% from the pretest average.

Alternate conception: *The electrons have precise orbits*

This alternate conception was held by 14% of the students and the modern view expressed by the scientists had to be reinforced after the posttest.

Alternate conception: *The electrons are just like planets around the sun.*

This alternate conception was held by 41% of the students, despite a decrease 9% from the pretest average. This was clarified during the posttest review.

Students' own: The students wrote various answers as a result of their incorrect perception and failed to choose the correct answer. 14% of the cohort belonged to this group.

Correct Reason: b. The fixed energy level of an electron keeps it moving along a certain path around the nucleus

This correct reason was chosen by 46% and the posttest average showed an increase of 28% from the pretest indicating that the analogy helped the students.

Alternate conception: *The electrons need a path to move without colliding with each other and the path taken by an electron is specific for a particular atomic radius*

These alternate conceptions were held by 27% and 14% of the cohort respectively. The analogy did not have a direct bearing on the concept and the students were required to extend their thinking to arrive at the correct answer, which did not happen. All the alternate conceptions and misconceptions were clarified to the students.

APPENDIX E. 6 a, b, c

The Quantum Mechanical Model of an Atom
Electronic Configuration

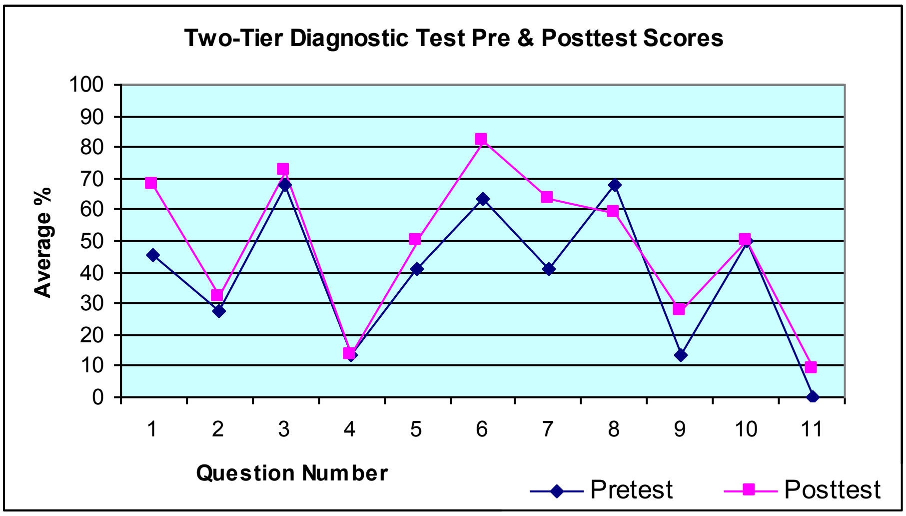


Figure E. 3. a

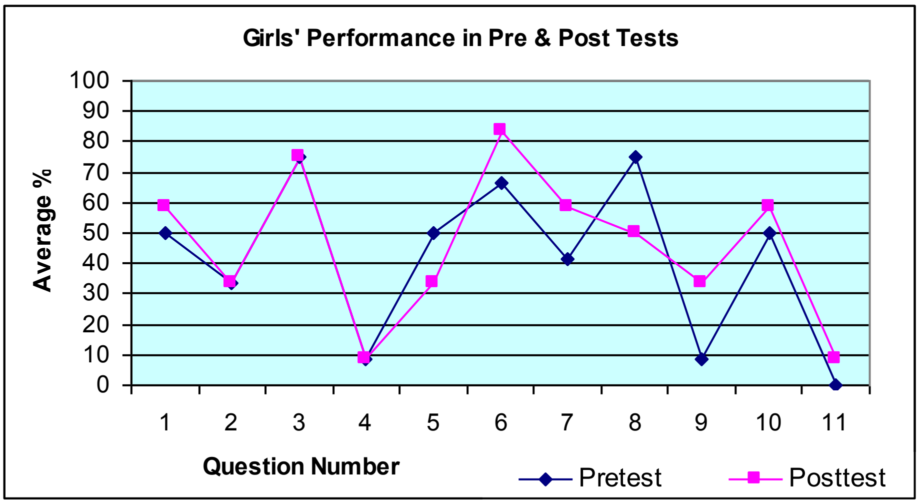


Figure E. 3. b

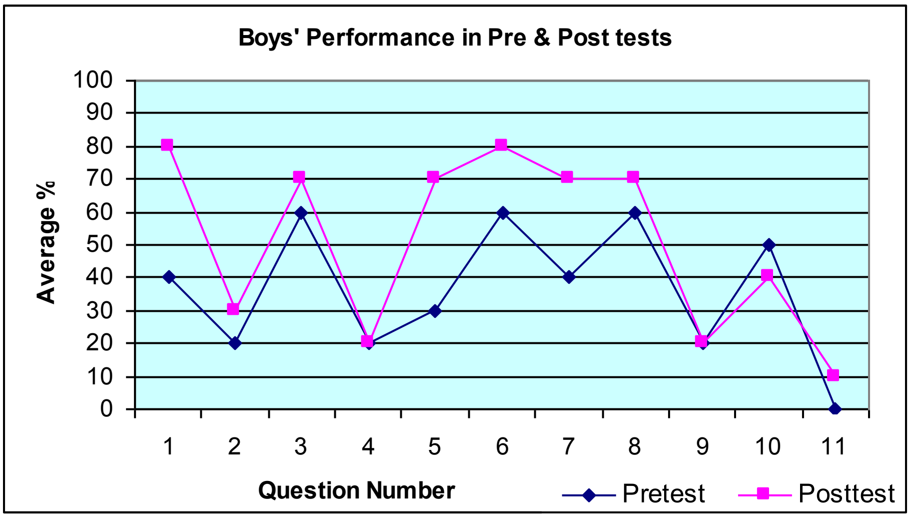


Figure E 3 c

APPENDIX E. 6 d, e

The Quantum Mechanical Model of an Atom
Electronic Configuration

Graph: Gender Differences

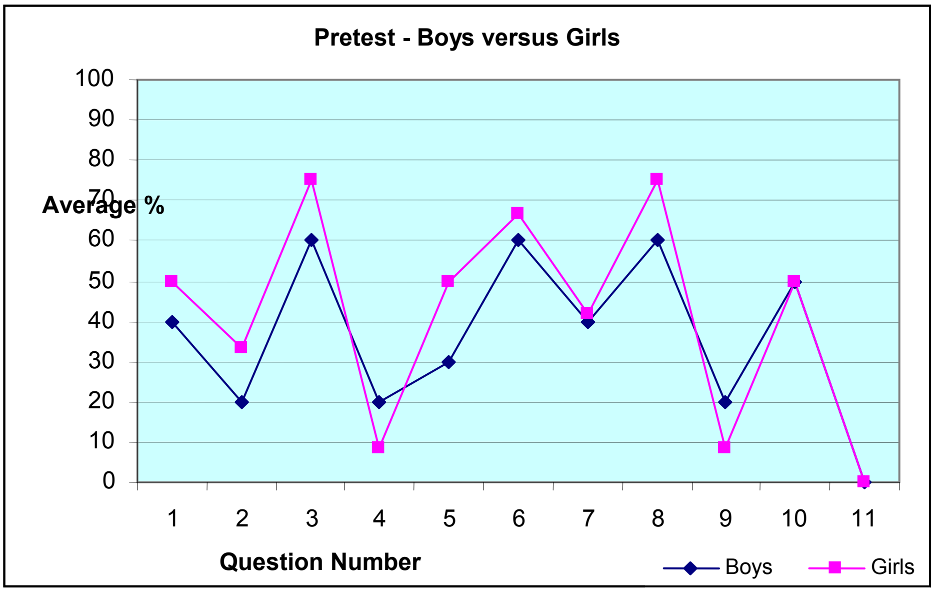


Figure E. 3. d

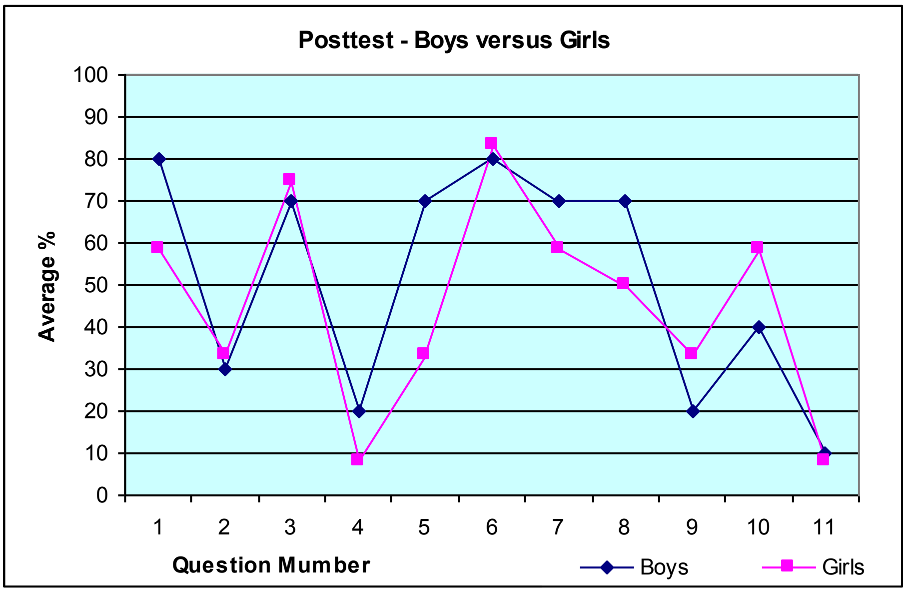


Figure E 3 e

APPENDIX E. 7

Review of the Analogy on the Mechanical Model of an atom

Electron Configuration

What do you know about the electron configuration in atoms?

When you viewed this analogy presentation of electron configuration, how did you figure out/ understand the:

1) Structure of an atom (nucleus, electron configuration, etc.):

____

____

____

____

2) Why do the electrons take their respective positions and don't go beyond that position?

____

____

3) Which orbital has the electrons having higher energy, 4d or 5s? How did you make this out? Is it that you remembered what you have learnt from teaching or from the analogy picture?

____

____

4) The way an atom behaves in order to get a stable electronic arrangement:

a) when it combines with a similar atom:

____

____

____

b) When it combines with the atom of another element:

____

____

____

5) Which **one** would you have preferred, the teacher teaching with such an analogy or simply teaching the details of electron configuration? Why?

____

____

____

____

6) Do you think that this analogy will help you to remember the information about atoms for a long time to answer questions on atoms in higher classes? why?

____

____

____

____

7) How does the structure of the tree and branches differ from the actual atom and its electron configuration?

____

____

____

____

____

8) Do you have any other comments on learning a difficult concept with an analogy?

____

____

____

____

____

APPENDIX E. 8

Statistical Analysis

Two-tier Diagnostic Testing

Mechanical Model of an atom Electron Configuration

Frequencies

Pretest - Frequency Tables

Q1pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	6	27.3	27.3	27.3
	1b	1	4.5	4.5	31.8
	1c	1	4.5	4.5	36.4
	2a	1	4.5	4.5	40.9
	2b	10	45.5	45.5	86.4
	2c	1	4.5	4.5	90.9
	3c	1	4.5	4.5	95.5
	4c	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q2pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.5	4.5	4.5
	2a	2	9.1	9.1	13.6
	2b	2	9.1	9.1	22.7
	2c	3	13.6	13.6	36.4
	3a	6	27.3	27.3	63.6
	3b	1	4.5	4.5	68.2
	3c	6	27.3	27.3	95.5
	4n	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q3pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.5	4.5	4.5
	2b	4	18.2	18.2	22.7
	3a	2	9.1	9.1	31.8
	3c	15	68.2	68.2	100.0
	Total	22	100.0	100.0	

Q4pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.5	4.5	4.5
	1b	3	13.6	13.6	18.2
	1c	2	9.1	9.1	27.3
	2a	2	9.1	9.1	36.4
	2b	1	4.5	4.5	40.9
	2c	2	9.1	9.1	50.0
	3a	1	4.5	4.5	54.5
	3b	8	36.4	36.4	90.9
	3c	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Q5pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1c	1	4.5	4.5	4.5
	1d	1	4.5	4.5	9.1
	2b	5	22.7	22.7	31.8
	2c	9	40.9	40.9	72.7
	3b	3	13.6	13.6	86.4
	3c	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Q6pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1c	3	13.6	13.6	13.6
	2a	1	4.5	4.5	18.2
	2b	1	4.5	4.5	22.7
	3b	14	63.6	63.6	86.4
	3c	2	9.1	9.1	95.5
	4d	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q7pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	4	18.2	18.2	18.2
	1b	2	9.1	9.1	27.3
	1c	1	4.5	4.5	31.8
	2a	1	4.5	4.5	36.4
	2b	9	40.9	40.9	77.3
	3a	1	4.5	4.5	81.8
	3b	4	18.2	18.2	100.0
	Total	22	100.0	100.0	

Q8pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	13.6	13.6	13.6
	2b	15	68.2	68.2	81.8
	3c	2	9.1	9.1	90.9
	3d	1	4.5	4.5	95.5
	4d	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q9pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	9.1	9.1	9.1
	1b	2	9.1	9.1	18.2
	1c	2	9.1	9.1	27.3
	2c	1	4.5	4.5	31.8
	3a	3	13.6	13.6	45.5
	3b	5	22.7	22.7	68.2
	3c	5	22.7	22.7	90.9
	3n	1	4.5	4.5	95.5
	4d	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q10pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	5	22.7	22.7	22.7
	1b	1	4.5	4.5	27.3
	1c	2	9.1	9.1	36.4
	2b	1	4.5	4.5	40.9
	3b	2	9.1	9.1	50.0
	3c	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

Q11pre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	9.1	9.1	9.1
	1c	2	9.1	9.1	18.2
	2a	1	4.5	4.5	22.7
	2b	3	13.6	13.6	36.4
	3a	3	13.6	13.6	50.0
	3b	3	13.6	13.6	63.6
	3c	5	22.7	22.7	86.4
	nn	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Posttest - Frequency Tables

Q1post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	13.6	13.6	13.6
	1b	1	4.5	4.5	18.2
	2a	1	4.5	4.5	22.7
	2b	15	68.2	68.2	90.9
	2c	1	4.5	4.5	95.5
	dd	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q2post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2a	2	9.1	9.1	9.1
	2b	1	4.5	4.5	13.6
	2c	2	9.1	9.1	22.7
	3a	7	31.8	31.8	54.5
	3b	5	22.7	22.7	77.3
	3c	5	22.7	22.7	100.0
	Total	22	100.0	100.0	

Q3post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	1	4.5	4.5	4.5
	2b	2	9.1	9.1	13.6
	3a	1	4.5	4.5	18.2
	3b	2	9.1	9.1	27.3
	3c	16	72.7	72.7	100.0
	Total	22	100.0	100.0	

Q4post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	13.6	13.6	13.6
	1b	3	13.6	13.6	27.3
	1c	2	9.1	9.1	36.4
	2a	1	4.5	4.5	40.9
	3a	2	9.1	9.1	50.0
	3b	10	45.5	45.5	95.5
	3c	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q5post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	2	9.1	9.1	9.1
	1b	1	4.5	4.5	13.6
	2b	4	18.2	18.2	31.8
	2c	11	50.0	50.0	81.8
	3b	1	4.5	4.5	86.4
	3c	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Q6post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1c	1	4.5	4.5	4.5
	1d	1	4.5	4.5	9.1
	2a	1	4.5	4.5	13.6
	3b	18	81.8	81.8	95.5
	3c	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Q7post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	3	13.6	13.6	13.6
	2a	1	4.5	4.5	18.2
	2b	14	63.6	63.6	81.8
	3b	2	9.1	9.1	90.9
	3c	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Q8post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	5	22.7	22.7	22.7
	1b	2	9.1	9.1	31.8
	2b	13	59.1	59.1	90.9
	3c	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Q9post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1b	2	9.1	9.1	9.1
	1c	2	9.1	9.1	18.2
	2b	6	27.3	27.3	45.5
	3a	6	27.3	27.3	72.7
	3b	2	9.1	9.1	81.8
	3c	4	18.2	18.2	100.0
	Total	22	100.0	100.0	

Q10post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	4	18.2	18.2	18.2
	1b	2	9.1	9.1	27.3
	1c	2	9.1	9.1	36.4
	2b	2	9.1	9.1	45.5
	2c	1	4.5	4.5	50.0
	3c	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

Q11post

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1a	4	18.2	18.2	18.2
	1b	2	9.1	9.1	27.3
	1c	1	4.5	4.5	31.8
	2b	3	13.6	13.6	45.5
	3a	2	9.1	9.1	54.5
	3b	5	22.7	22.7	77.3
	3c	2	9.1	9.1	86.4
	dd	1	4.5	4.5	90.9
	nn	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Frequencies

Statistics

		Pre1	Pre2	Pre3	Pre4	Pre5	Pre6	Pre7	Pre8	Pre9	Pre10	Pre11
N	Valid	22	22	22	22	22	22	22	22	22	22	22
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		.4545	.2727	.6818	.1818	.4091	.6364	.4091	.6818	.1364	.5000	.0000
Std. Deviation		.50965	.45584	.47673	.39477	.50324	.49237	.50324	.47673	.35125	.51177	.00000

Frequency Tables

Pre1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	12	54.5	54.5	54.5
	1.00	10	45.5	45.5	100.0
	Total	22	100.0	100.0	

Pre2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	16	72.7	72.7	72.7
	1.00	6	27.3	27.3	100.0
	Total	22	100.0	100.0	

Pre3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	7	31.8	31.8	31.8
	1.00	15	68.2	68.2	100.0
	Total	22	100.0	100.0	

Pre4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	18	81.8	81.8	81.8
	1.00	4	18.2	18.2	100.0
	Total	22	100.0	100.0	

Pre5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	13	59.1	59.1	59.1
	1.00	9	40.9	40.9	100.0
	Total	22	100.0	100.0	

Pre6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	8	36.4	36.4	36.4
	1.00	14	63.6	63.6	100.0
	Total	22	100.0	100.0	

Pre7

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	13	59.1	59.1	59.1
	1.00	9	40.9	40.9	100.0
	Total	22	100.0	100.0	

Pre8

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	7	31.8	31.8	31.8
	1.00	15	68.2	68.2	100.0
	Total	22	100.0	100.0	

Pre9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	19	86.4	86.4	86.4
	1.00	3	13.6	13.6	100.0
	Total	22	100.0	100.0	

Pre10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	11	50.0	50.0	50.0
	1.00	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

Pre11

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	22	100.0	100.0	100.0

Frequencies

Statistics

		Post1	Post2	Post3	Post4	Post5	Post6	Post7	Post8	Post9	Post10	Post11
N	Valid	22	22	22	22	22	22	22	22	22	22	22
	Missing	0	0	0	0	0	0	0	0	0	0	0
Mean		.6818	.3182	.7273	.2727	.5000	.8182	.6364	.5909	.2727	.5000	.0909
Std. Deviation		.47673	.47673	.45584	.45584	.51177	.39477	.49237	.50324	.45584	.51177	.29424

Frequency Tables

Post1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	7	31.8	31.8	31.8
	1.00	15	68.2	68.2	100.0
	Total	22	100.0	100.0	

Post2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	15	68.2	68.2	68.2
	1.00	7	31.8	31.8	100.0
	Total	22	100.0	100.0	

Post3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	6	27.3	27.3	27.3
	1.00	16	72.7	72.7	100.0
	Total	22	100.0	100.0	

Post4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	16	72.7	72.7	72.7
	1.00	6	27.3	27.3	100.0
	Total	22	100.0	100.0	

Post5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	11	50.0	50.0	50.0
	1.00	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

Post6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	4	18.2	18.2	18.2
	1.00	18	81.8	81.8	100.0
	Total	22	100.0	100.0	

Post7

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	8	36.4	36.4	36.4
	1.00	14	63.6	63.6	100.0
	Total	22	100.0	100.0	

Post8

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	9	40.9	40.9	40.9
	1.00	13	59.1	59.1	100.0
	Total	22	100.0	100.0	

Post9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	16	72.7	72.7	72.7
	1.00	6	27.3	27.3	100.0
	Total	22	100.0	100.0	

Post10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	11	50.0	50.0	50.0
	1.00	11	50.0	50.0	100.0
	Total	22	100.0	100.0	

Post11

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	20	90.9	90.9	90.9
	1.00	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

Frequencies

Statistics

		TOTALpre	TOTALpost
N	Valid	22	22
	Missing	0	0
Mean		4.3636	5.4091
Std. Deviation		2.40130	2.59412

Frequency Table

TOTALpre

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	3	13.6	13.6	13.6
	2.00	3	13.6	13.6	27.3
	3.00	2	9.1	9.1	36.4
	4.00	5	22.7	22.7	59.1
	5.00	1	4.5	4.5	63.6
	6.00	4	18.2	18.2	81.8
	7.00	1	4.5	4.5	86.4
	8.00	2	9.1	9.1	95.5
	9.00	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

TOTALpost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	1	4.5	4.5	4.5
	2.00	2	9.1	9.1	13.6
	3.00	2	9.1	9.1	22.7
	4.00	4	18.2	18.2	40.9
	5.00	4	18.2	18.2	59.1
	6.00	2	9.1	9.1	68.2
	7.00	1	4.5	4.5	72.7
	8.00	3	13.6	13.6	86.4
	9.00	1	4.5	4.5	90.9
	10.00	2	9.1	9.1	100.0
	Total	22	100.0	100.0	

APPENDIX F

(Relates to Action Research in Chapters 1, 3 & 8)

APPENDIX F. 1

Name ________________________ Class ____________________ Date ___________

Importance of Science. Answer the following questions. **Circle** the answer that **you think** is right.

A. Do you think that **knowledge of Science is useful** in the following areas?

1 Choice of food and cooking	Yes	Sometimes	No	
2 Health and hygiene	Yes	Sometimes	No	
3 Protection and cure from diseases	Yes	Sometimes	No	
4 Clothing and dressmaking	Yes	Sometimes	No	
5 Building constructions, carpentry, metal work	Yes	Sometimes	No	
6 Gardening/Agriculture, poultry and pet care	Yes	Sometimes	No	
7 Pollution and weed control	Yes	Sometimes	No	
8 Saving wildlife and environment	Yes	Sometimes	No	
9 Almost in all areas of one's life	Yes	Sometimes	No	
10 Making earth a better place to live	Yes	Sometimes	No	/10

About my studies

1 I enjoy my life at school	Yes	Sometimes	No	
2 I enjoy my studies at school	Yes	Sometimes	No	
3 My studies will help me to have a better life	Yes	Sometimes	No	
4 My studies will not help me to have a better life	Yes	Sometimes	No	
5 I am not sure why I come to school	Yes	Sometimes	No	/5

C. Complete the following sentences:

1 I like Science because____
____

2. I don't like Science because ____
____

3 I might like Science, if ____
____

4. I will never like Science because ____
____

5. I am not able to write my Science tests/ assignments well, because _______________
____

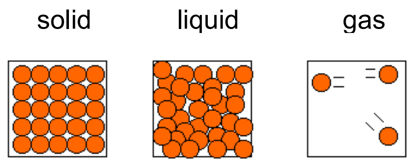
/5

Please Turn over

These are **the things that I remember about my science classes** at my primary school.
List them below:

These are the **science lessons or what I learnt in science** that I still remember:

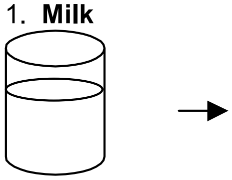
APPENDIX F. 2 Year 8 Matter



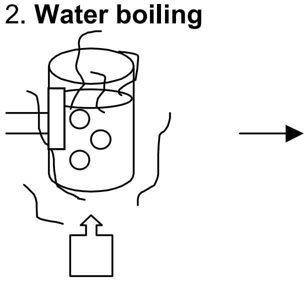
As we have learnt in this chapter, solids, liquids and gases would look like the above, if you have special eyes to look at the things around us.

You would like to look at the following with your SPECIAL EYES and draw diagrams of what you see:

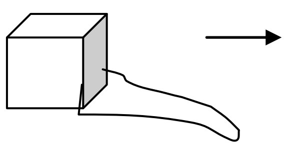
1. **Milk** Your diagrams



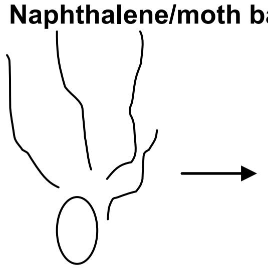
2. **Water boiling**



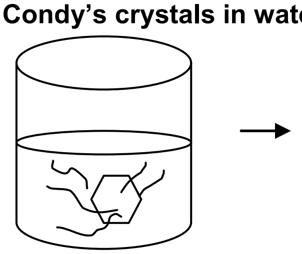
3. **Ice melting**



4. **Naphthalene/moth ball gradually disappearing**



5. **Condy's crystals in water**



6. This is the way the clouds are formed:

7. Wet clothes dry in this way:

8. I smell the barbeque from next-door!

9. Oops! The round up from my garden has reached the creek!

10. My room smells of air freshener!

Problem solving

Sketch or write the steps and show how you would solve the following problems. Explain scientifically why you think that this is the best way to solve this problem.

1. You have sprayed a poisonous insecticide on a plant. You do not want any one to breathe in the poison. What would you do? Write or draw and show your solution in steps:

Step1: ____

____

Step 2: ____

____

Step 3: ____

____

Diagram

2. You have invited your friends for a party. When you cooked, you burnt the food. Now, the house smells of burnt food. You have to get rid of the smell in 10 minutes before your friends arrive. You have just a few drops of deodorant at the bottom of the bottle. What would you do? Write your solution in steps:

Step1: ____

____

Step 2: ____

____

Step 3: ____

____

Diagram

3. You have to install an air conditioner in your room. Where would you fix it? Close to the floor or at 4 feet above the ground or close to the ceiling. Why?

____

____

4. In case of fever, the doctors place ice packs on the forehead, if the temperature of the body goes above 102 Fahrenheit, What happens as a result? Why?

____

____

5. Millions of gallons of water escape from the surface of Ross (river) dam every day. What can be done to prevent this loss? Can you think of a solution?

____

____

APPENDIX F. 3 Concept Map

Chicken meat and bacterial diseases

<u>This is my knowledge:</u>
News on television: Chickens carry bacteria that could kill people if the chicken is not cooked thoroughly.

My mind analyses the situation:
I should pay much attention and buy fresh chicken.
I should cook the chicken thoroughly.
I should clean the kitchen table thoroughly, after cutting the chicken.
Should I buy the chemical cleaner that was advertised on TV?
? Should I completely avoid buying chicken?

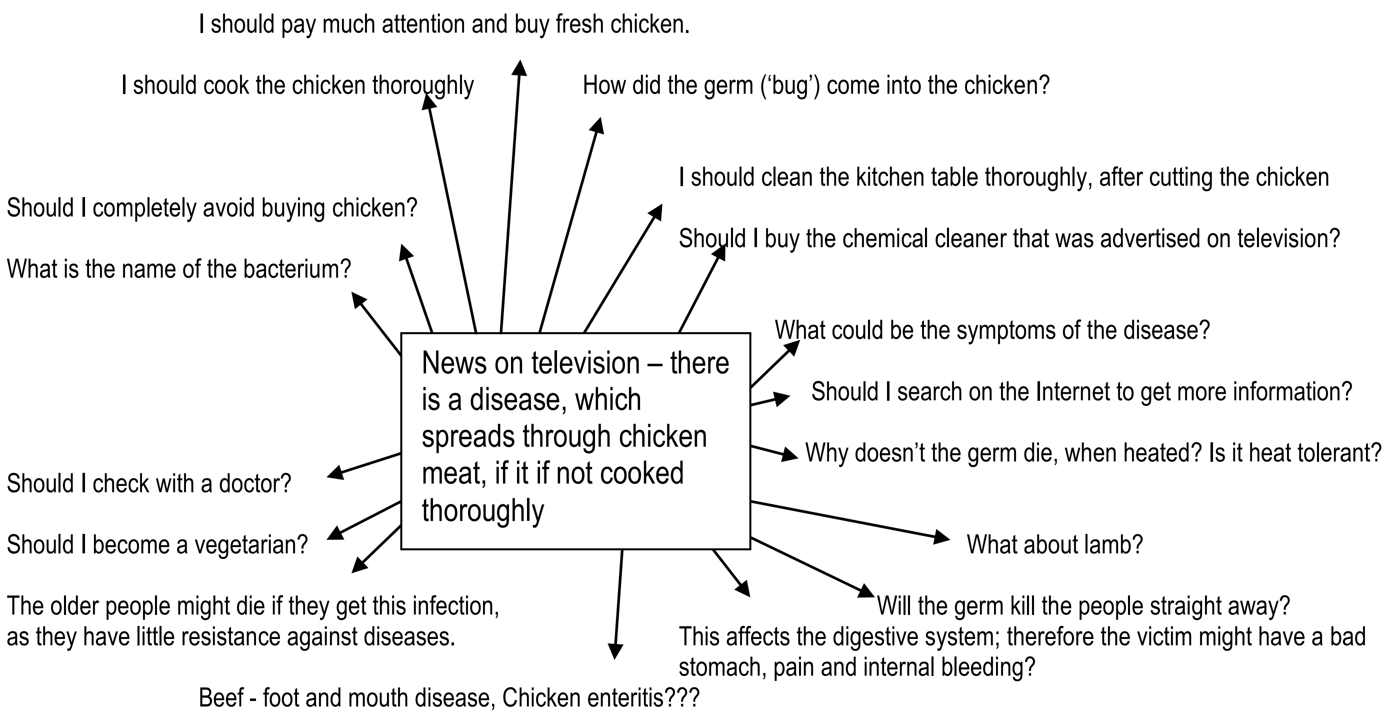
My mind associates the following with the chicken incident:
What is the name of the bacteria?
How did it come into the chicken?
Why doesn't it die, when heated?
What could be the symptoms of the disease?
Should I check with a doctor to protect myself from this bacterium?
Should I search on the Internet?
This affects the digestive system; therefore the victim might have a bad stomach, pain or internal bleeding?
Could it kill the people straight away?
The older people might die if they get this infection, as they have little resistance against diseases.
Beef-foot and mouth disease, Chicken enteritis. What about lamb? Should I become a vegetarian?
This goes on and on…

Every bit of information brings many other associated information to our minds. This is very important in the learning of Science, because we build our knowledge on what we know already.

This should tell you that you should click on the 'save' button in your brain, when you come to know of something important to you and your life either in class or elsewhere. Unless you tell your brain to save, you will not remember this information later.

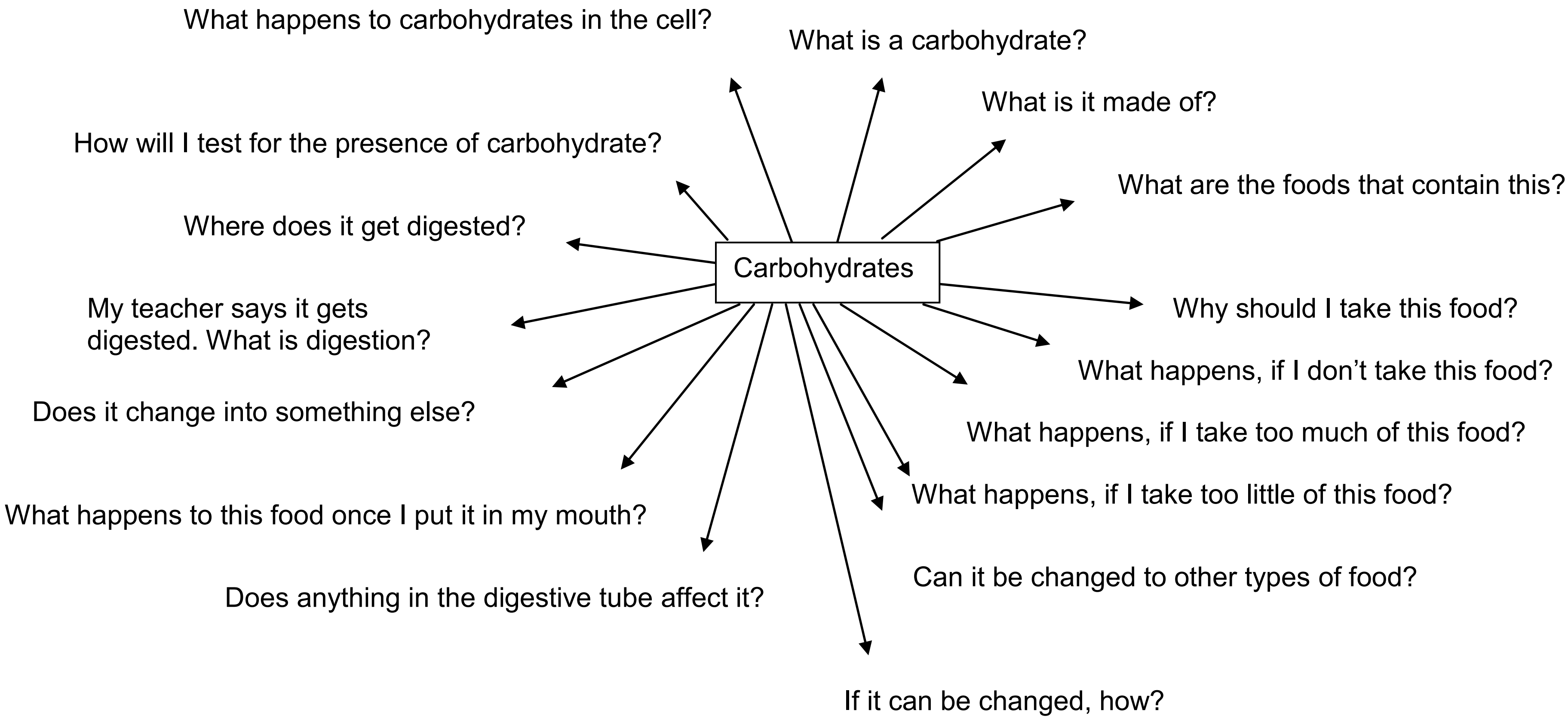
Concept Map: A concept map shows how we associate what we know with the new information that we receive and how our brain processes the information. This is my concept associated with the chicken disease.

<u>Concept Map for Chicken Enteritis</u>



Note: All that my mind brought out has been put beside the arrow. You will do the same with your concept map.

Another example of concept map on **CARBOHYDRATES**



Now, would you be able to develop a concept map on diseases in the space below?

DISEASES

APPENDIX F. 4

SCIENCE MOTIVATION

Name:____ Year: 10

Please give **practicable suggestions** to motivate the students to learn science, based on your learning experience.

a) Did/didn't you give full attention to learning science in school?

____

b) What would have made you participate better in class?

1____

2.____

3.____

4.____

5.____

c) How many people other than your teacher helped you in learning science? Who are they?

____

____

d) Did you ask your parents/care giver for help to complete science tasks such as assignments?

____

e) If 'Yes', did you receive help, whenever asked for it?

____

____

f) If 'No', Why?

____

____

g) Do you think that parents/care giver should sit with their children and help with their homework, etc.?

____

h) If 'Yes', till what level (eg. Year 8) or age?

____

i) What do you think is the reason for students lacking motivation in class to learn science? Is it only science or other subjects too?

____

____

Please turn over

j) If you were to give advice as to how to motivate students to learn science, what would be your advice to the Department of education/Principal/teacher? Feel free to write all that would encourage a student to learn science.

APPENDIX F. 5

Multiple Intelligences

NAME______________________________ Date ____________________

If you agree with the statement, **place a tick** on the left, if you don't agree **leave it blank**

Section 1	Section 2
…..I enjoy grouping things by common traits. …..Ecological issues are important to me. …..Hiking and camping are enjoyable. …..I enjoy working in a garden. …..I believe preserving our National parks is important. …..Putting things in the higher order makes sense to me. …..Animals are important in my life. …..My home has a recycling system in place. …..I enjoy studying about plants animals. …..I spend a great deal of time outdoors.	…..I easily pick up on patterns. …..I focus in on noise and sounds. …..Moving to a beat is easy for me. …..I have always been interested in playing an instrument. …..The intonation/tempo of poetry intrigues me. …..I remember things by putting them in a rhyme …..To concentrate is difficult, while the radio or TV is on. …..I enjoy many kinds of music. …..Musicals are more interesting than dramatic plays. ..…..Remembering song lyrics is easy for me.

Section 1 Total: ………….   Section 2 Total: …………

Section 3	Section 4
…..I keep my things neat and tidy. …..Step by step directions are a big help. …..Solving problems (anywhere)comes easily for me. …..I get easily frustrated with disorganised people. …..I can complete calculations quickly in my head. …..Puzzles requiring reasoning are fun …..I can't begin my assignment until all my questions are answered …..Structure and order help me to be successful. ….. I find working on a computer spreadsheet or database rewarding. …..Things have to make sense to me or I am dissatisfied.	….. I learn best interacting with others. ….. he more, the merrier. ….. Study groups are very productive for me . ….. I enjoy chat rooms. …..Participating in politics is important. ….. Television and radio talk shows are enjoyable. ….. I always like to work in a team. ….. I dislike working alone. ….. Clubs and extra curricular activities are fun. …..I pay attention to social issues and causes.

Section 5

….I enjoy making things with my hands.

…..Sitting still for a long time is difficult for me.

…..I enjoy outdoor games and sports.

…..I value non-verbal communication such as sign language.

…..A fit body is important for a fit mind.

…..Arts and crafts are enjoyable pastimes

…..Expression through dance is beautiful.

…..I like working with tools.

…..I live an active lifestyle.

……I learn by doing.

Section 5 Total: ………….

Section 6

….. I enjoy reading all kinds of materials.

…..Taking notes help me remember and understand.

…..I faithfully contact friends through letters and/or e-mail.

…..It is easy for me to explain my ideas to others.

….. I keep a journal.

…..Word puzzles like crosswords and jumbles are fun.

. …..I write for pleasure.

….. I enjoy playing with words like puns, *anagrams and **spoonerisms.

…..Foreign languages interest me.

…..Debates and public speaking are activities I like to participate in.

Section 6 Total: ..………….

Section 7

….. I am keenly aware of my moral beliefs.

…..I learn best when I have an emotional attachment to the subject.

…..Fairness is important to me.

…..My attitude affects how I learn.

…..Social justice issues concern me.

…..Working alone can be just as productive as working in a group.

…..I need to know why I should do something before I agree to do it.

…..When I believe in something, I will give 100% effort to it

…..I like to be involved in causes that help others

….. I am willing to protest or sign a petition to change a wrong thing to right.

Section 7 Total: ………….

Section 8

…..I can imagine ideas in my mind.

……Rearranging a room is fun for me.

…..I enjoy creating art using varied media .

…..I remember well, using graphic organisers

…..Performance art can be very gratifying.

…..Spreadsheets are great for making charts, graphs and tables .

…..Three dimensional puzzles bring me such enjoyment.

…..Music videos are very stimulating.

……I can recall things in mental pictures.

…..I am good at reading maps and blueprints.

Section 8 Total: ……………..

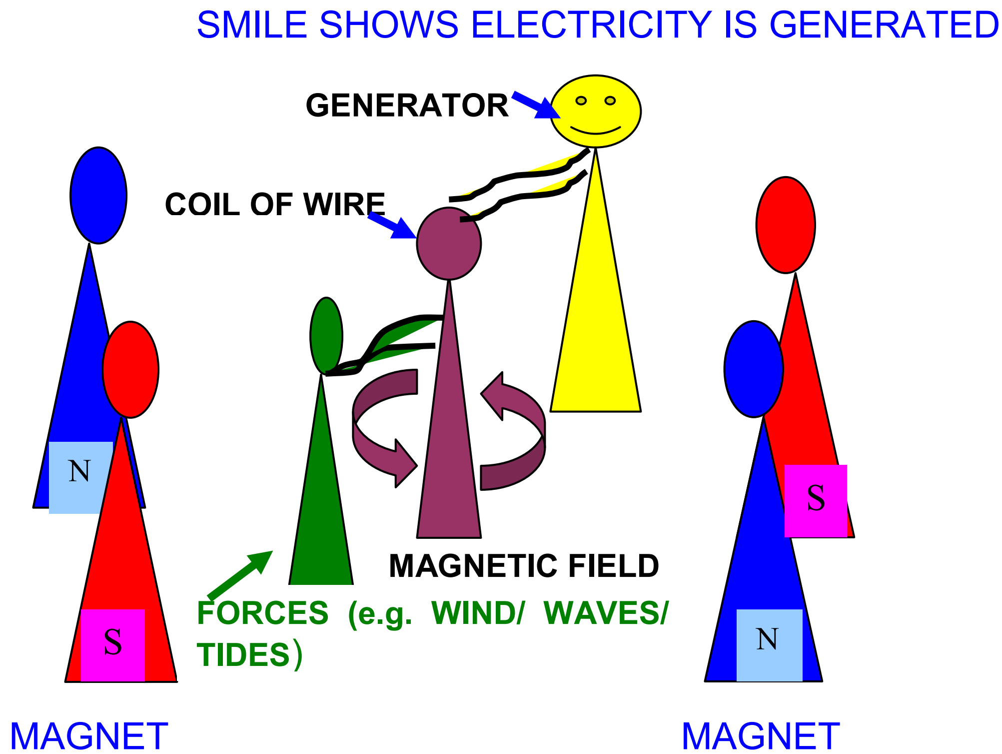
http://surfaquarium.com/MI invent.htm

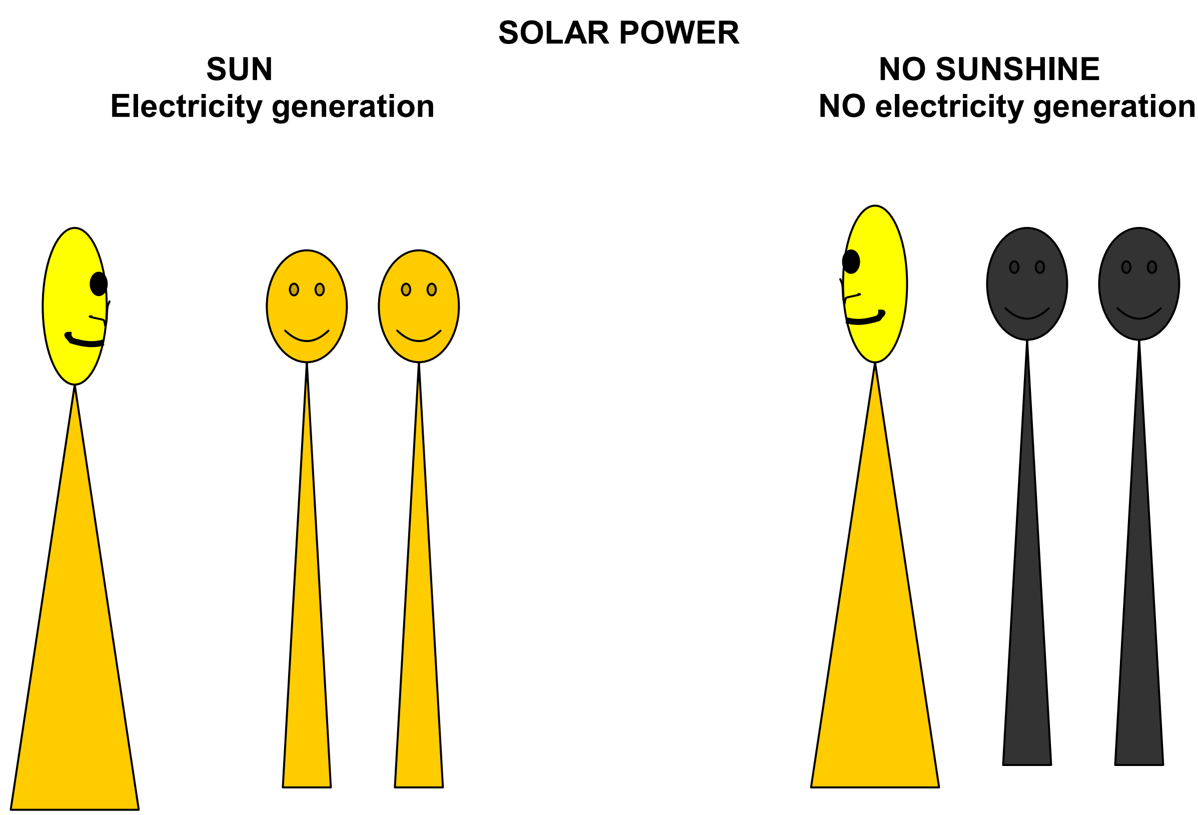
*Anagram: A word or phrase formed by reordering the letters of another word or phrase, such as satin to stain.

**Spoonerisms: These are phrases, sentences, or words in language with sounds swapped eg: 'Go and shake a tower' changes to 'Go and take a shower'.

APPENDIX F. 6

ROLE PLAY on ELECTRICITY GENERATION





All the above figures represent students

APPENDIX F. 7

Students' opinion on learning science

This is to find out whether my students enjoyed their science lessons and found it as a means of increasing their scientific knowledge and removing their misconceptions (mistaken belief/wrong idea). You don't have to give your name, but please be honest in your opinion.

Gender: Male/Female Age: ___________ Year level: Grade 8 Date: 07/12/2007

Science is my best subject/one of the best subjects. Yes/No

Your opinion	Verymuch	Moderately	Not at all
1. I enjoyed my science lessons through out the year.			
2. Learning science will help me *to know why and how* things happen in my life.			
3. I *want to know more* about science so that *I can use the concepts* (ideas) in my real life and live a better and healthier life.			
4. The interesting part of science is *performing investigations.*			
5. The interesting part of science is *listening to real life stories related to the topic* we are learning.			
6. The *diagrams* the teacher draws or shows while explaining the topic makes me more interested in science.			
7. I prefer *animations* related to the topic shown with the explanation and this will capture my attention.			
8. I prefer *video clips* related to the topic shown with the explanation and this will capture my attention.			
9. I prefer *an analogy (a comparison in the real world)* related to the topic *explained to me without a picture* to capture my attention.			
10. I prefer *an analogy (a comparison in the real world)* related to the topic *explained to me with a picture* to capture my attention.			
11. I prefer the analogy *to be a game* like the one we played for the atom.			
12. I prefer the analogy *to be a hands on activity* with materials.			
13. Analogies make the complex topics simple and easy to understand.			
14. I prefer an *interactive science class*, interacting with the students and teacher, sharing my views and experiences on the topic.			
15. I got interested in science only this year, since the way we learnt science is different from the past.			
16. The reason is: 1. The topics are interesting			
2. I am able to understand what is being taught and the topics are at my level of understanding.			
3. I have performed more hands on activities such as experiments, research and assignments.			
4. I have the freedom to get help from friends in my class, when I need help.			
5. I have the freedom to get help from the teacher, whenever I need.			

If you want to add anything about learning science this year . . . ____

____

Billy Bob

Year 8 Matter

solid liquid gas

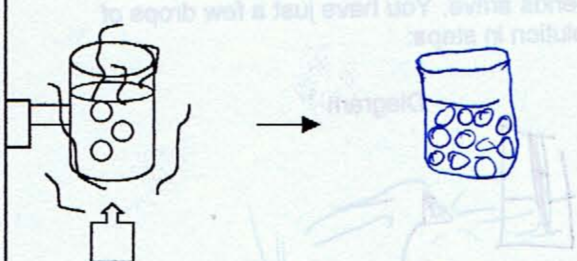
As we have learnt in this chapter, solids, liquids and gases would look like the above, if you have special eyes to look at the things around us.

You would like to look at the following with your SPECIAL EYES and draw diagrams of what you see:

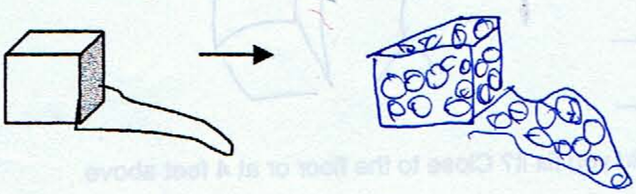
1. Milk

Your diagrams

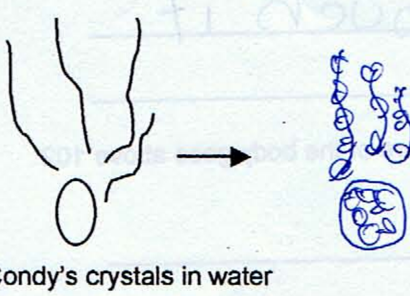
2. Water boiling



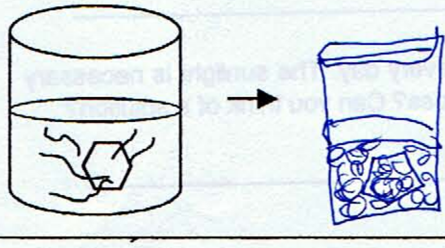
3. Ice melting



4. Naphthalene/moth ball gradually disappearing

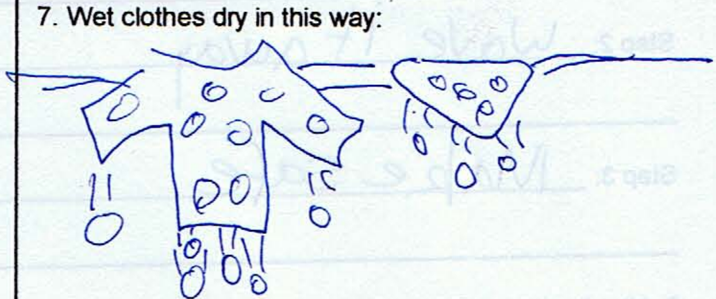


5. Condy's crystals in water

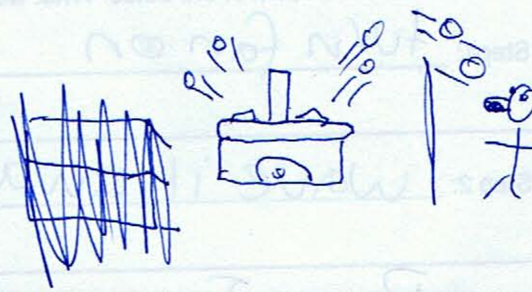


6. This is the way the clouds are formed:

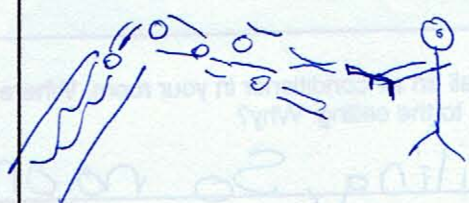
7. Wet clothes dry in this way:



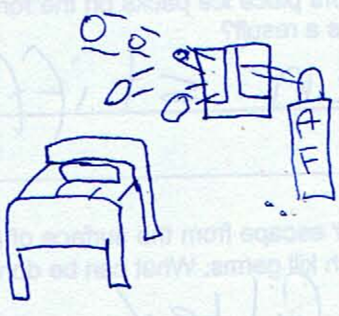
8. I smell the barbeque from next-door!



9. Oops! The round up from my garden has reached the creek!



10. My room smells of air freshener!



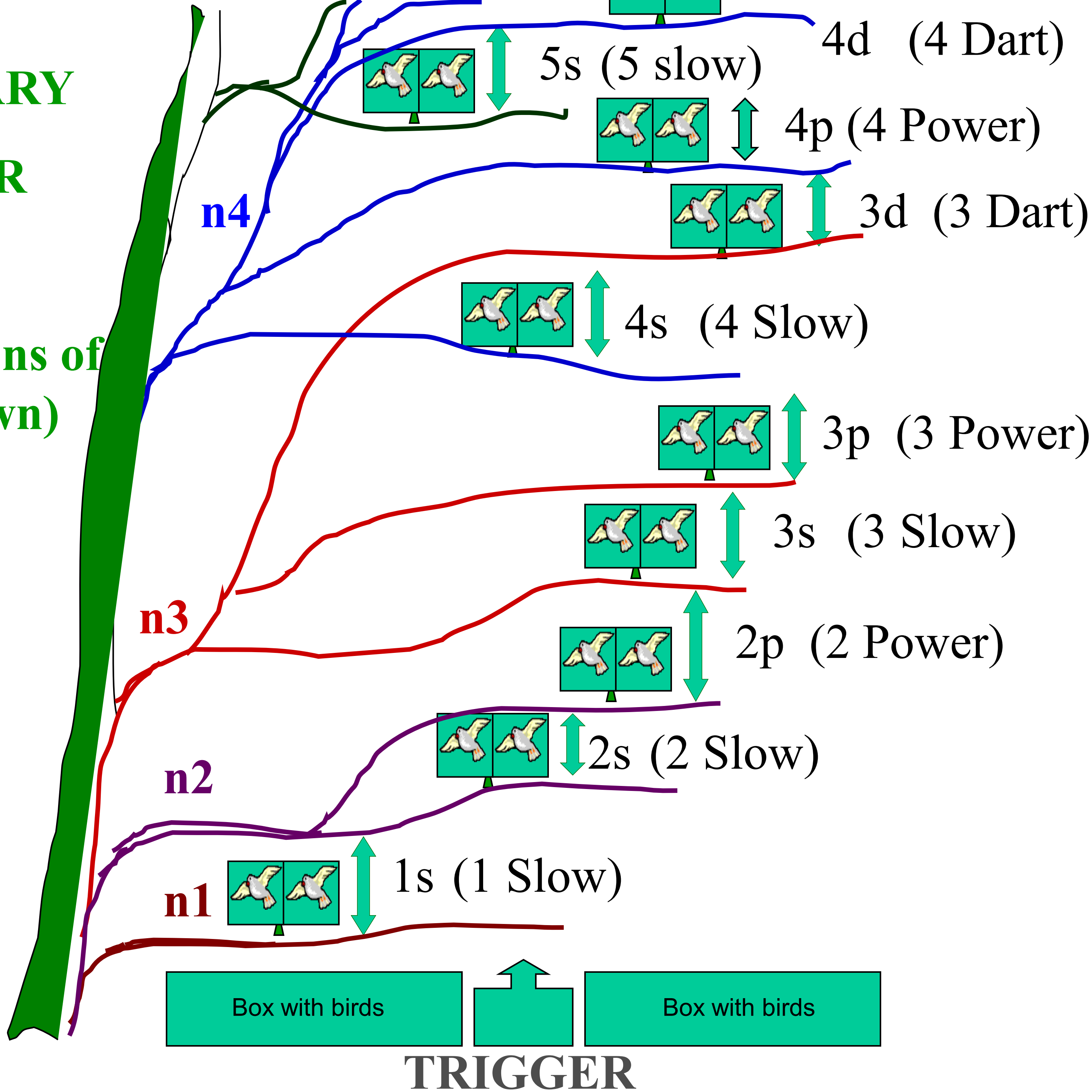
Appendix E.2.

THE QUANTUM MECHANICAL MODEL OF THE ATOM

ELECTRON CONFIGURATION

AN IMAGINARY COMPUTER GAME

(only the positions of the cages shown)

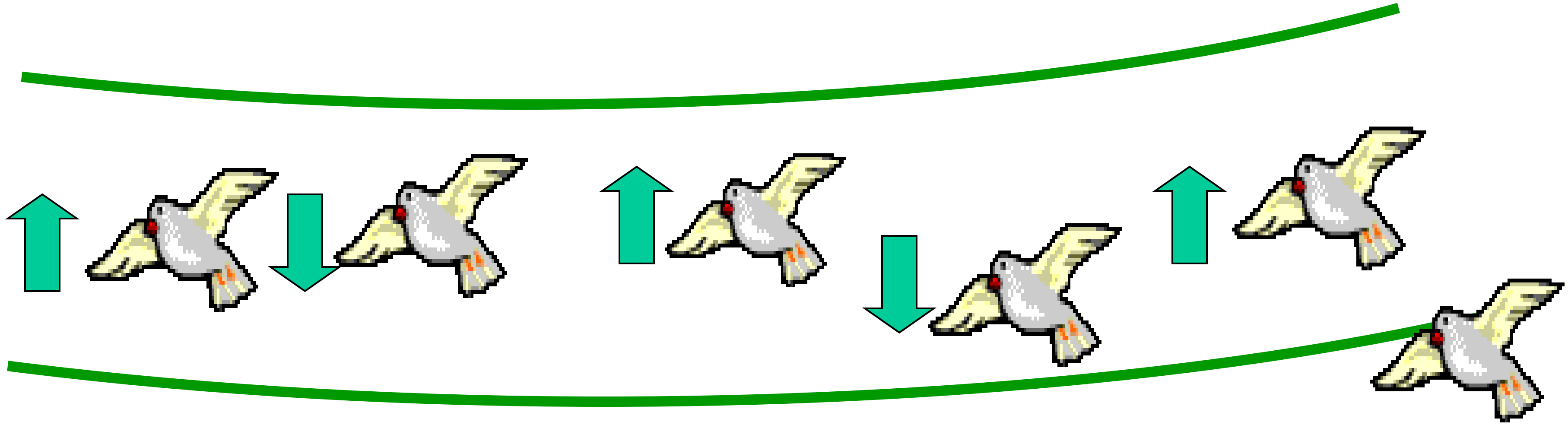


Electrons and Spinning Birds (Analogy-an imaginary computer game)

When the trigger is released, the birds take off from the boxes and occupy different cages found between the branches and spin in opposite directions.

The heights they can fly depends on the energy they possess and this decides the cages they occupy.

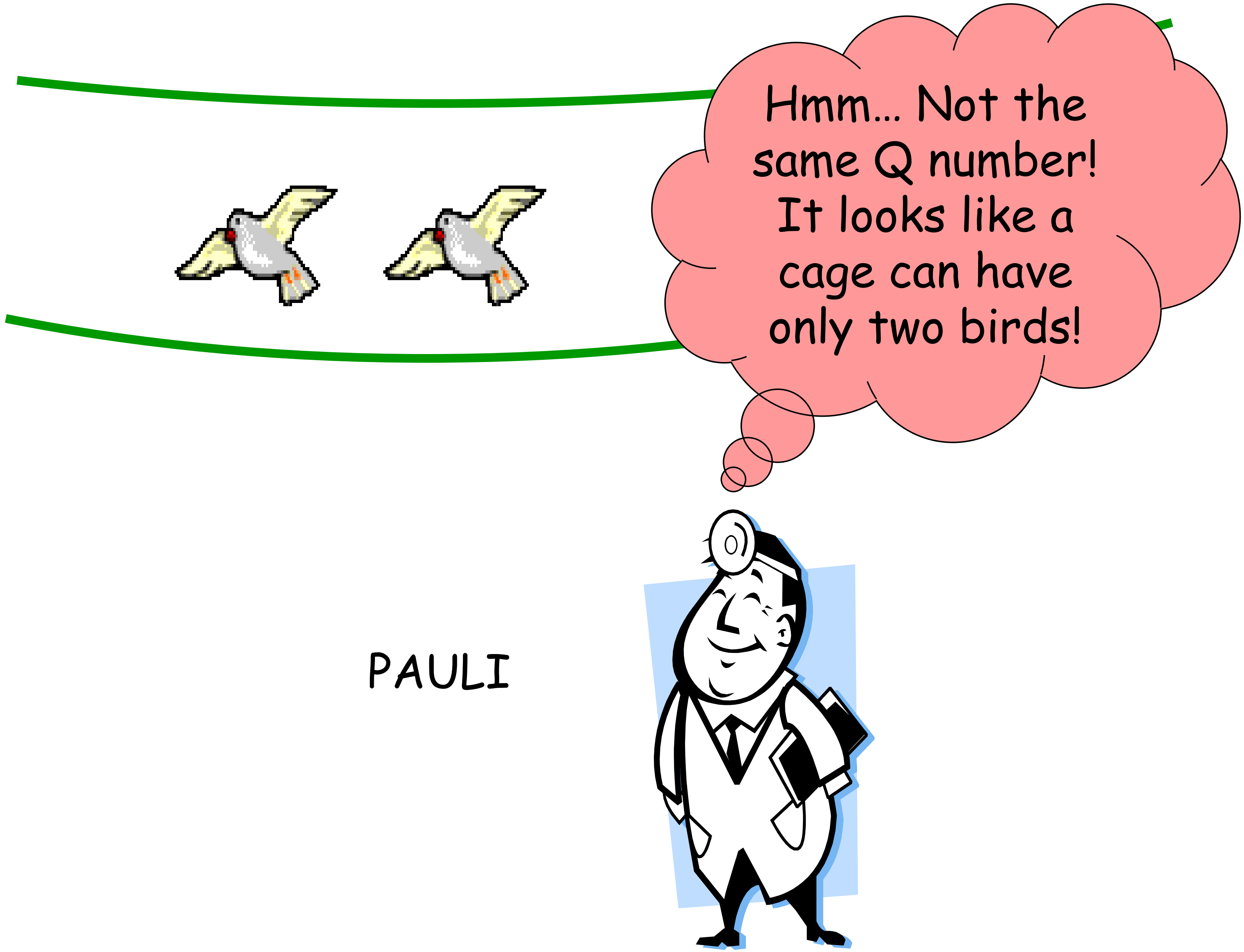
Birds are compared to electrons, branches, the quantum levels and the cages, the orbitals.

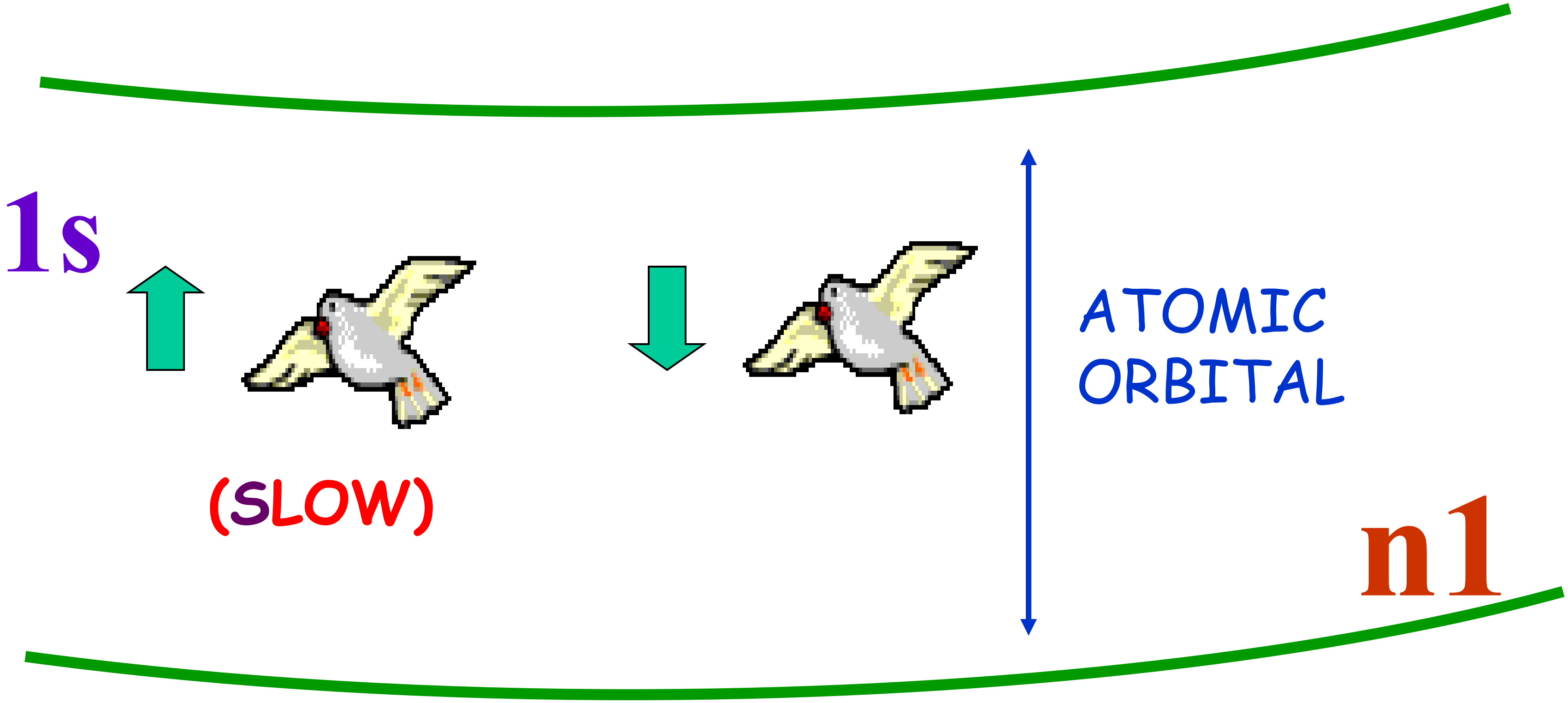


MR. HUND

Birds with equal energy! One bird flies to its position and start to spin vertically; then its partner with opposite spin joins and spins parallel to the first!

Hello, I've just found out that 'aufau' means the birds on the bottom cages of each branch have the lowest energy. They are not able to fly higher than that!


Hmm... Not the same Q number! It looks like a cage can have only two birds!
PAULI

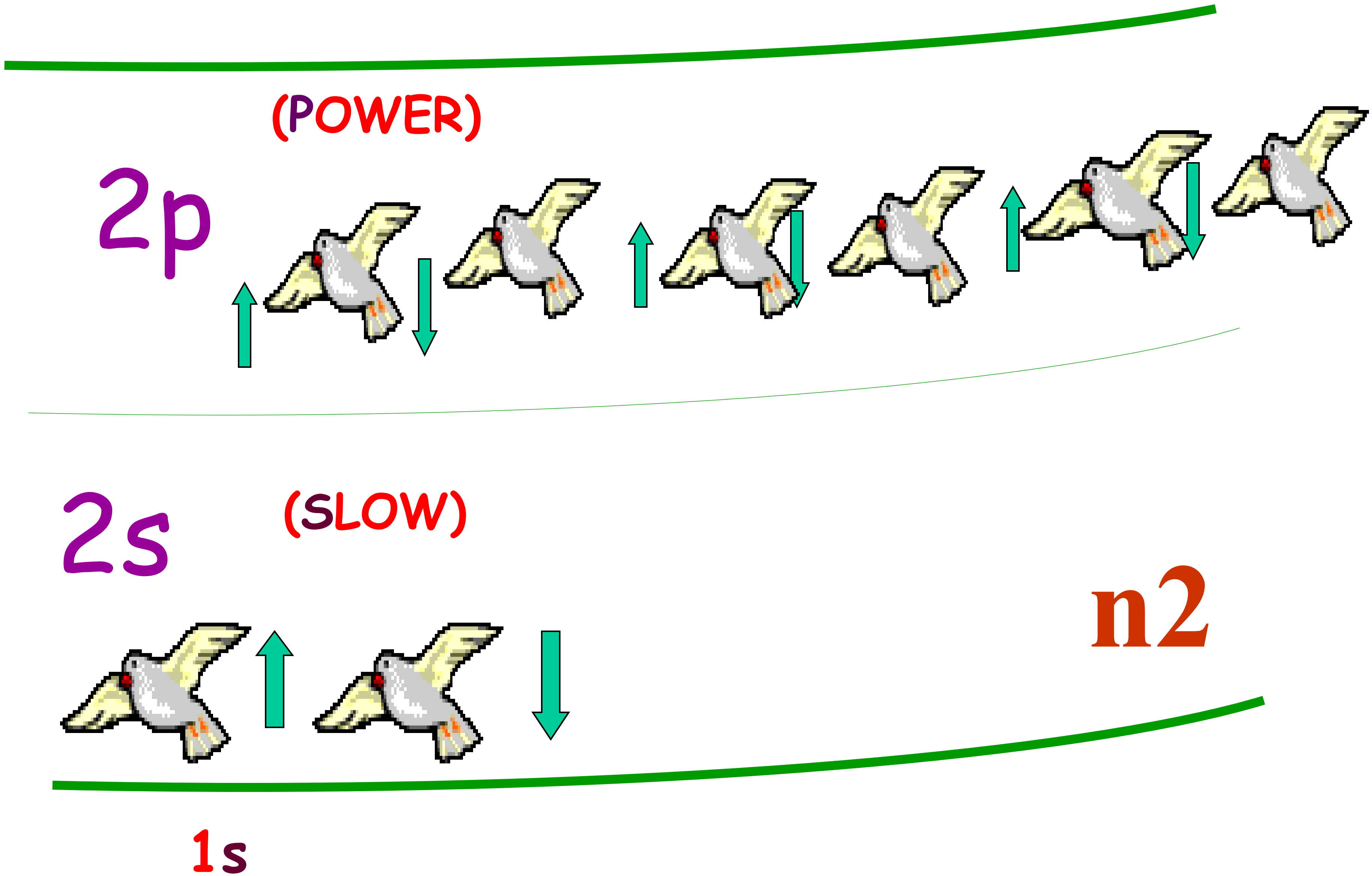


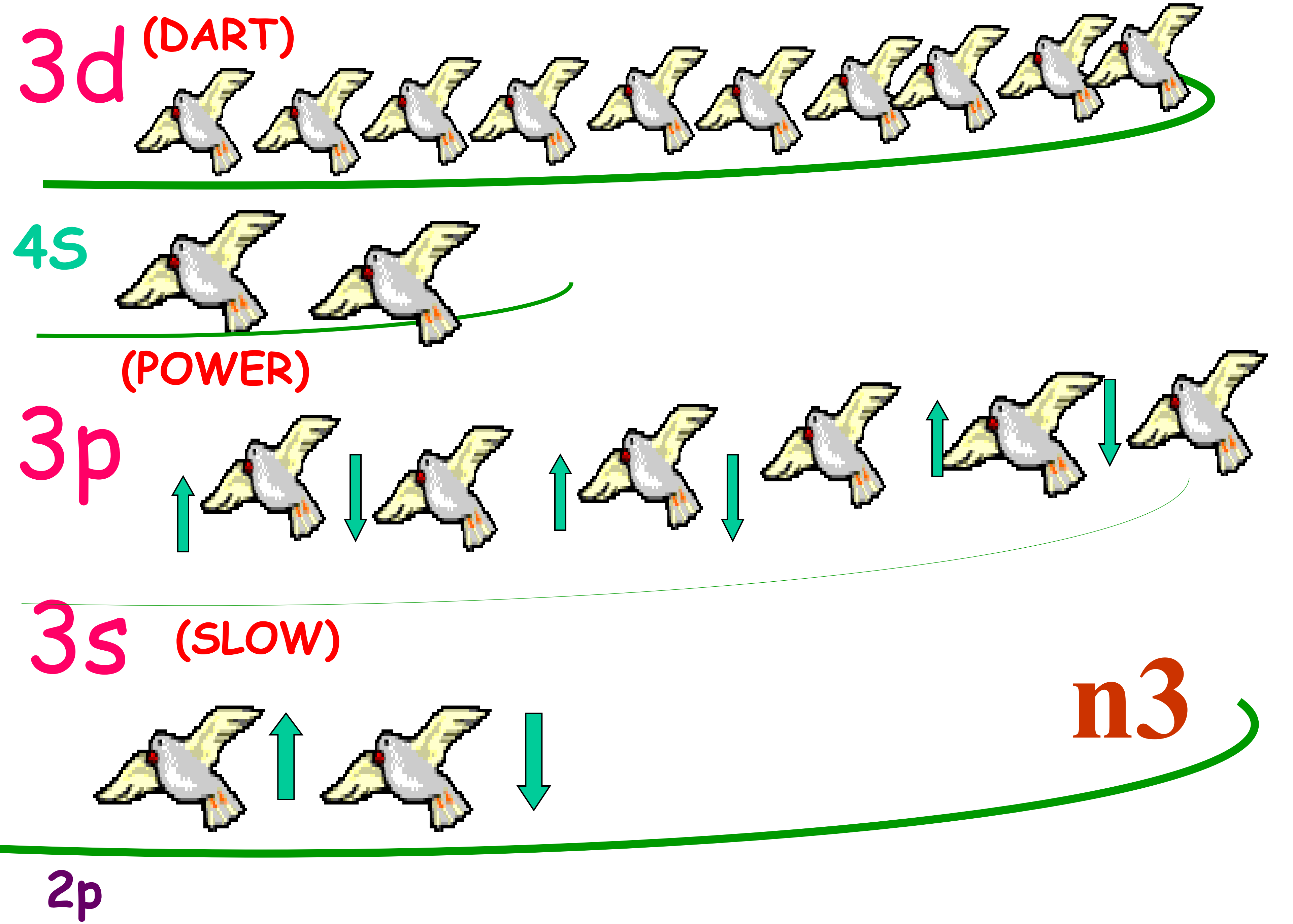
Birds → Electrons

n1 Branch → Principal Energy level

1s Spinning position → Energy sublevel

Opposite arrows show vertical spinning in the opposite directions.


(POWER)
2p
2s
(SLOW)
n2
1s


3d
(DART)
4s
(POWER)
3p
3s
(SLOW)
n3
2p

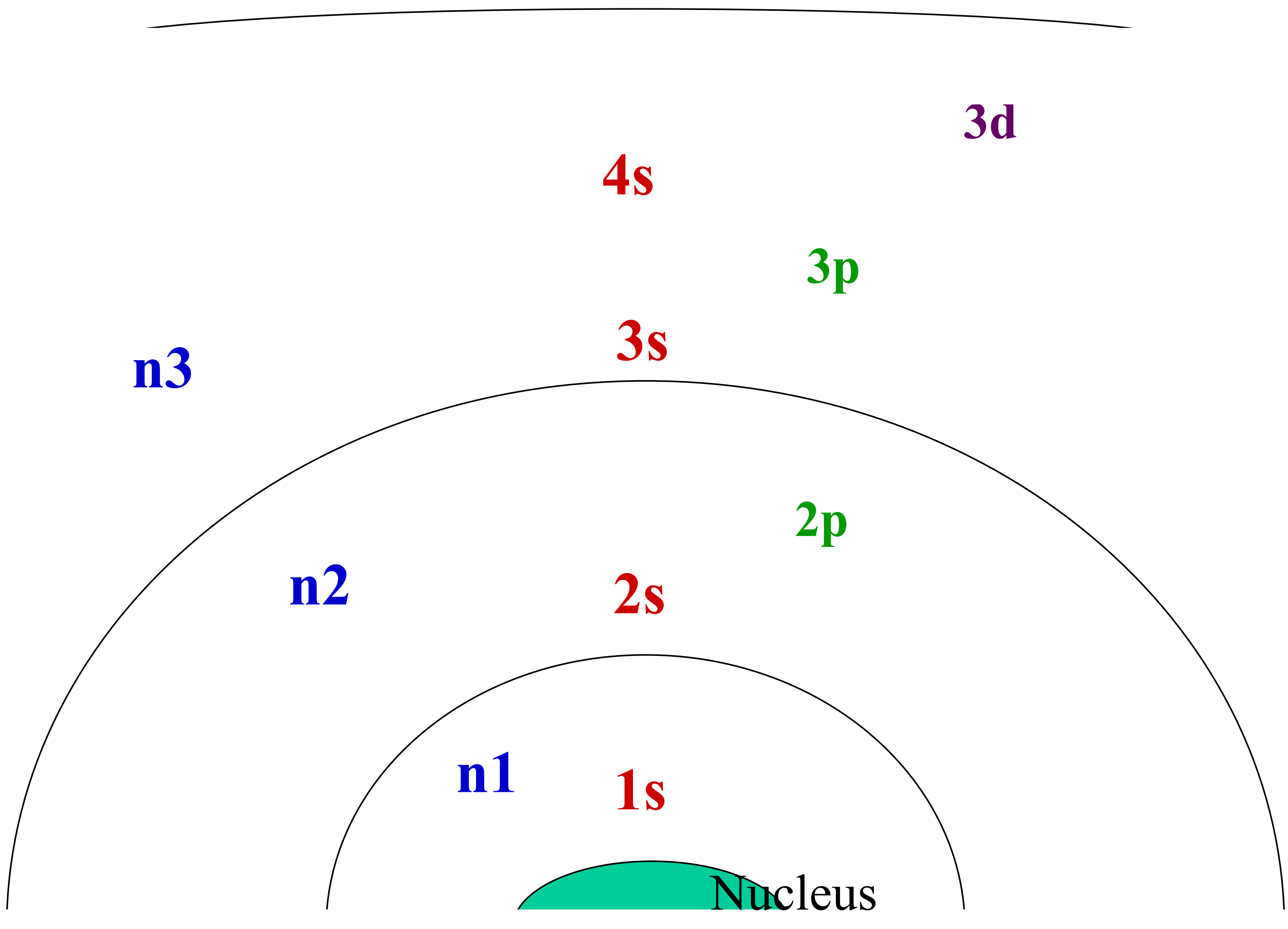
Analog mapping

Create a table and ***guess*** the targets for the following analogs:

Analog	**Target**
Birds	Electrons
Branch	
Cage	
Spinning position	
Slow level	
Power level	
Dart level	
Fastest level	
A pair of birds	

Electron Distribution

Approximate Positions



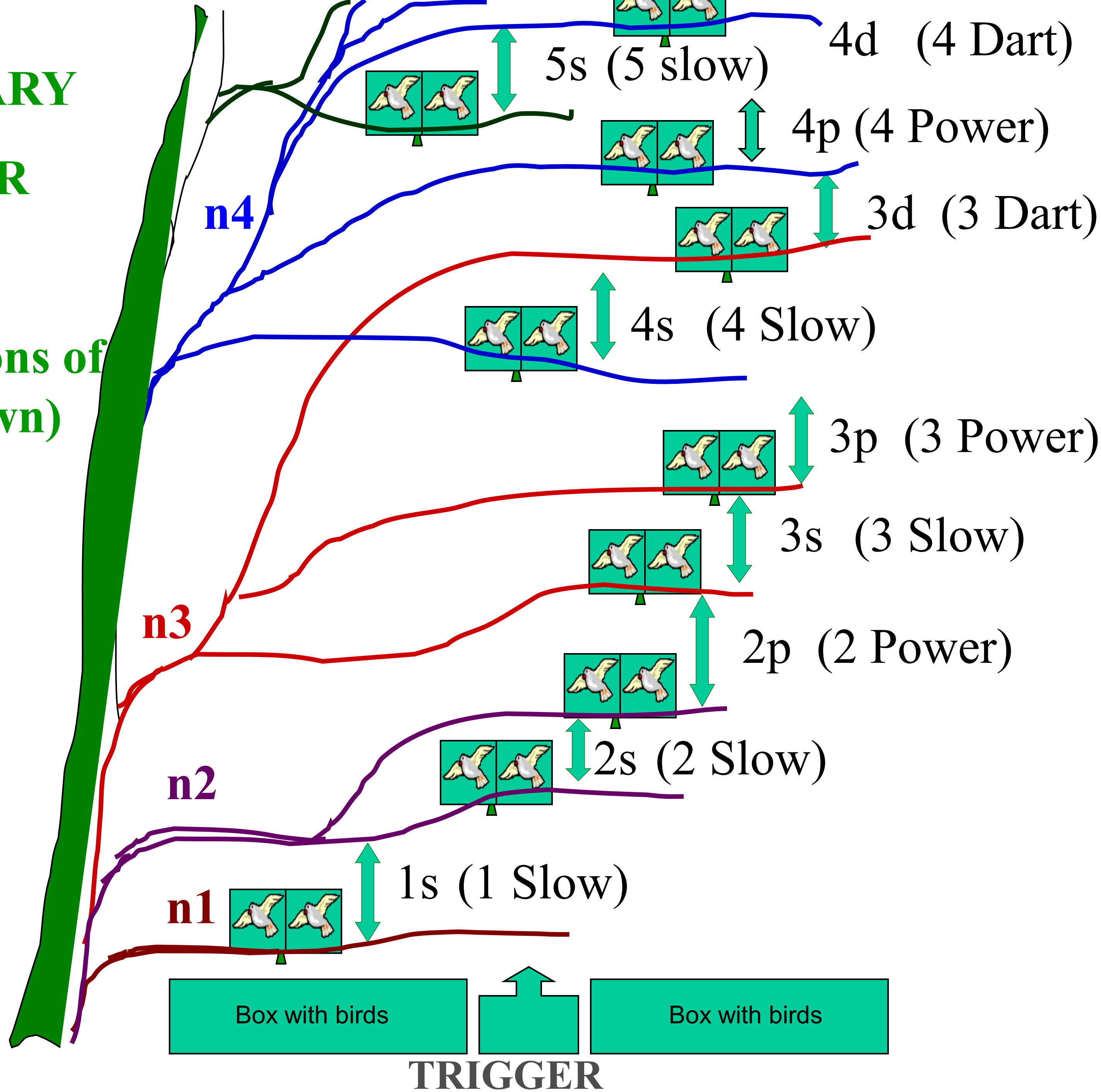
Appendix. E.1

THE QUANTUM MECHANICAL MODEL OF THE ATOM

ELECTRON CONFIGURATION

AN IMAGINARY COMPUTER GAME

(only the positions of the cages shown)



Electrons and Spinning Birds
(Analogy is an imaginary computer game)

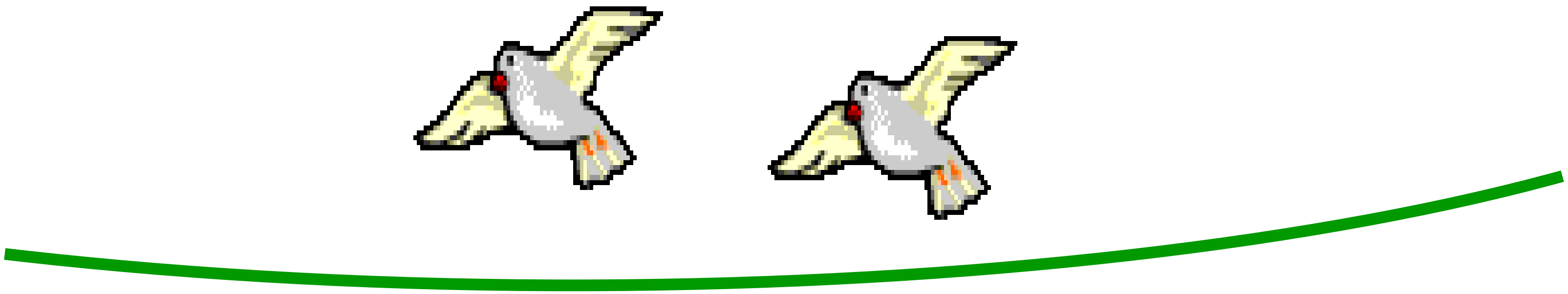
When the trigger is released, the birds take off from the boxes and occupy different cages found between the branches and spin in opposite directions.

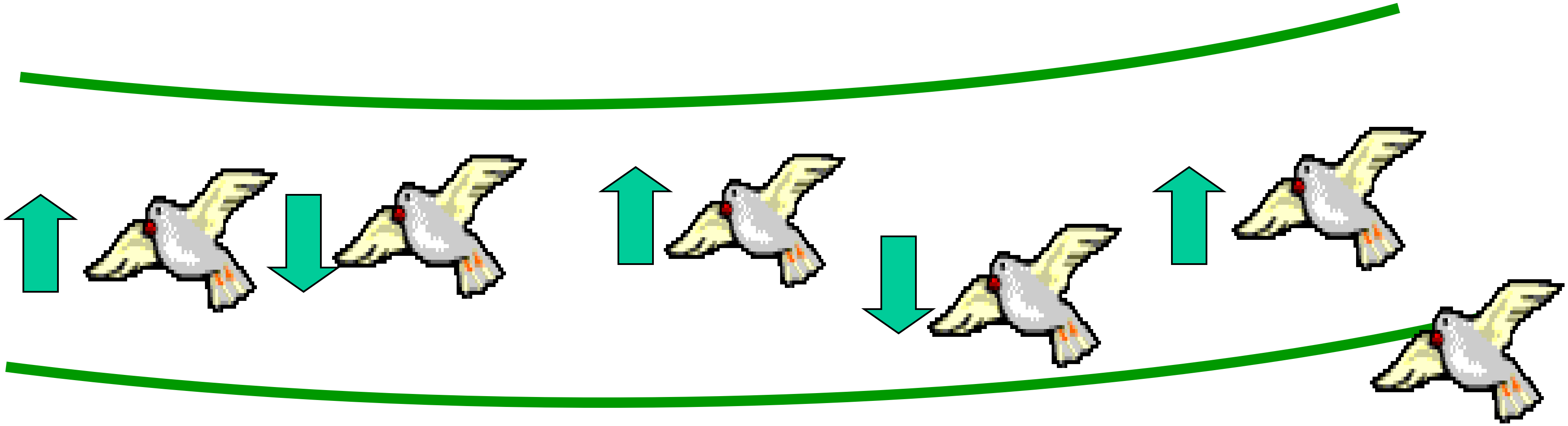
The heights they can fly depends on the energy they possess and this decides the cages they occupy.

Birds are compared to electrons, branches, the quantum levels and the cages, the orbitals.

1 Slow cage

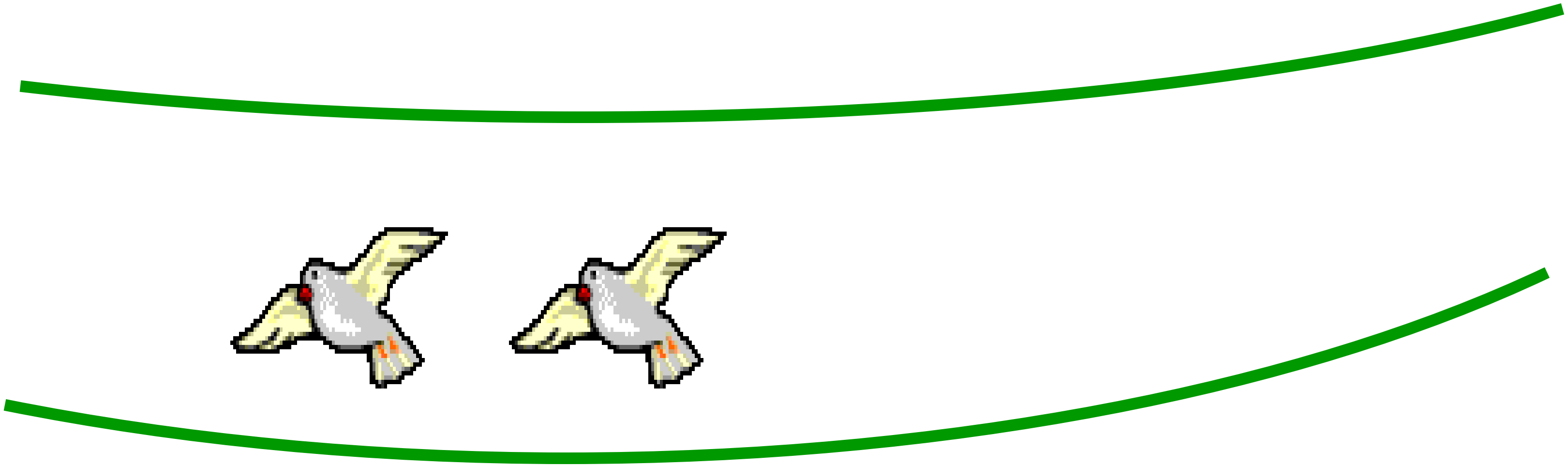
2 Slow cage



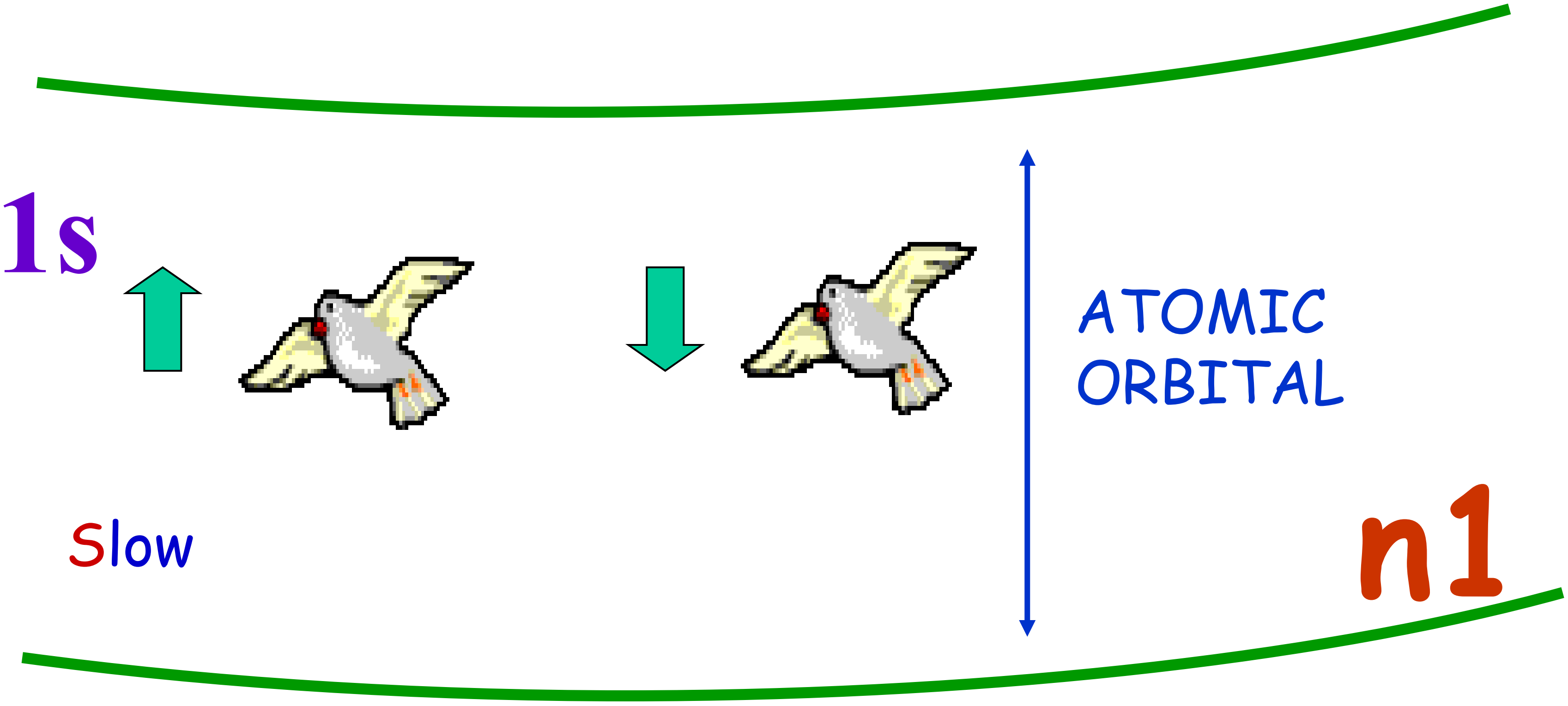


2 Power cages

One enters the cage first and starts to spin vertically; it is joined by the next, which starts to spin in the opposite direction!



Only two birds in a cage!

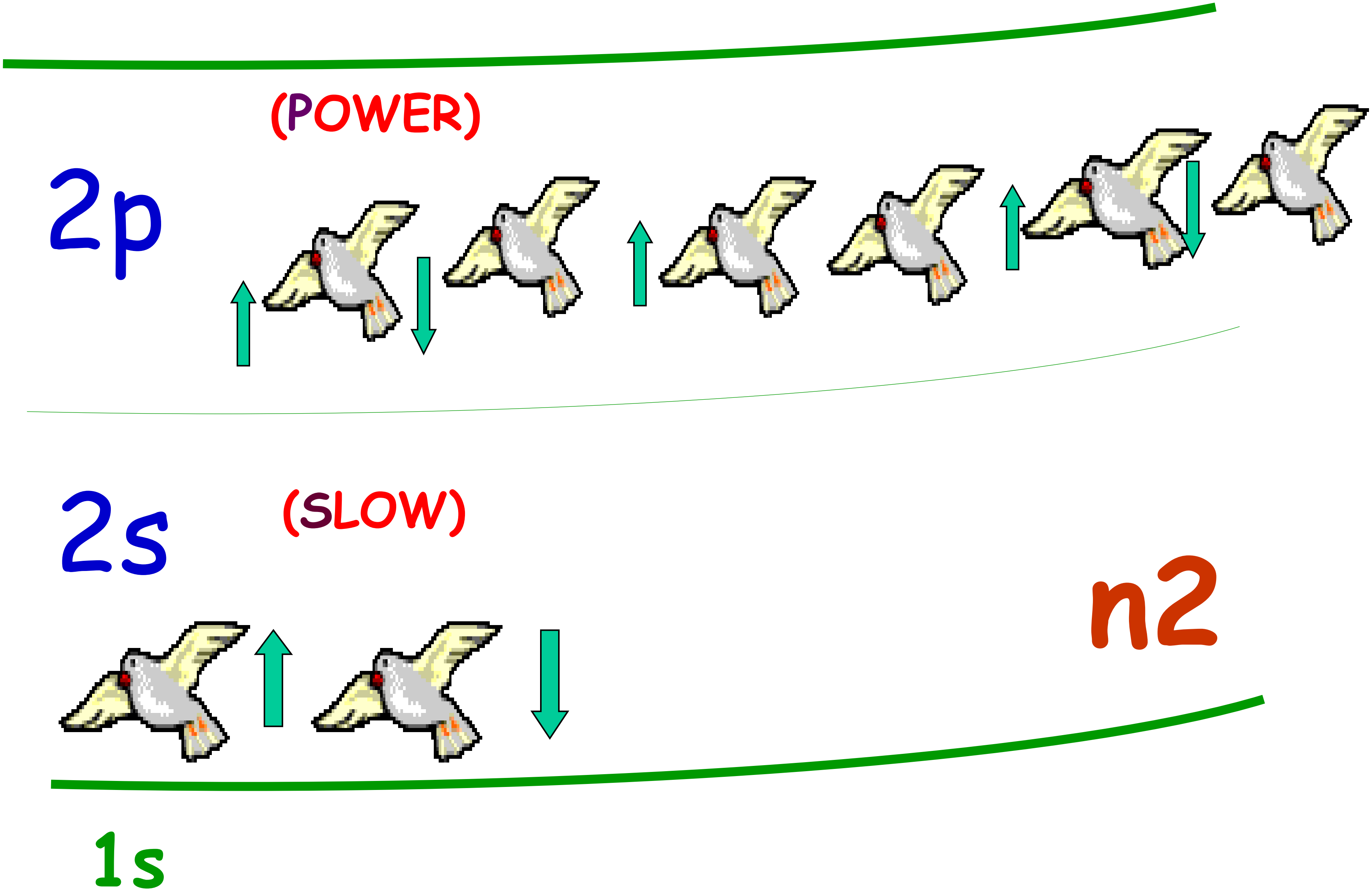


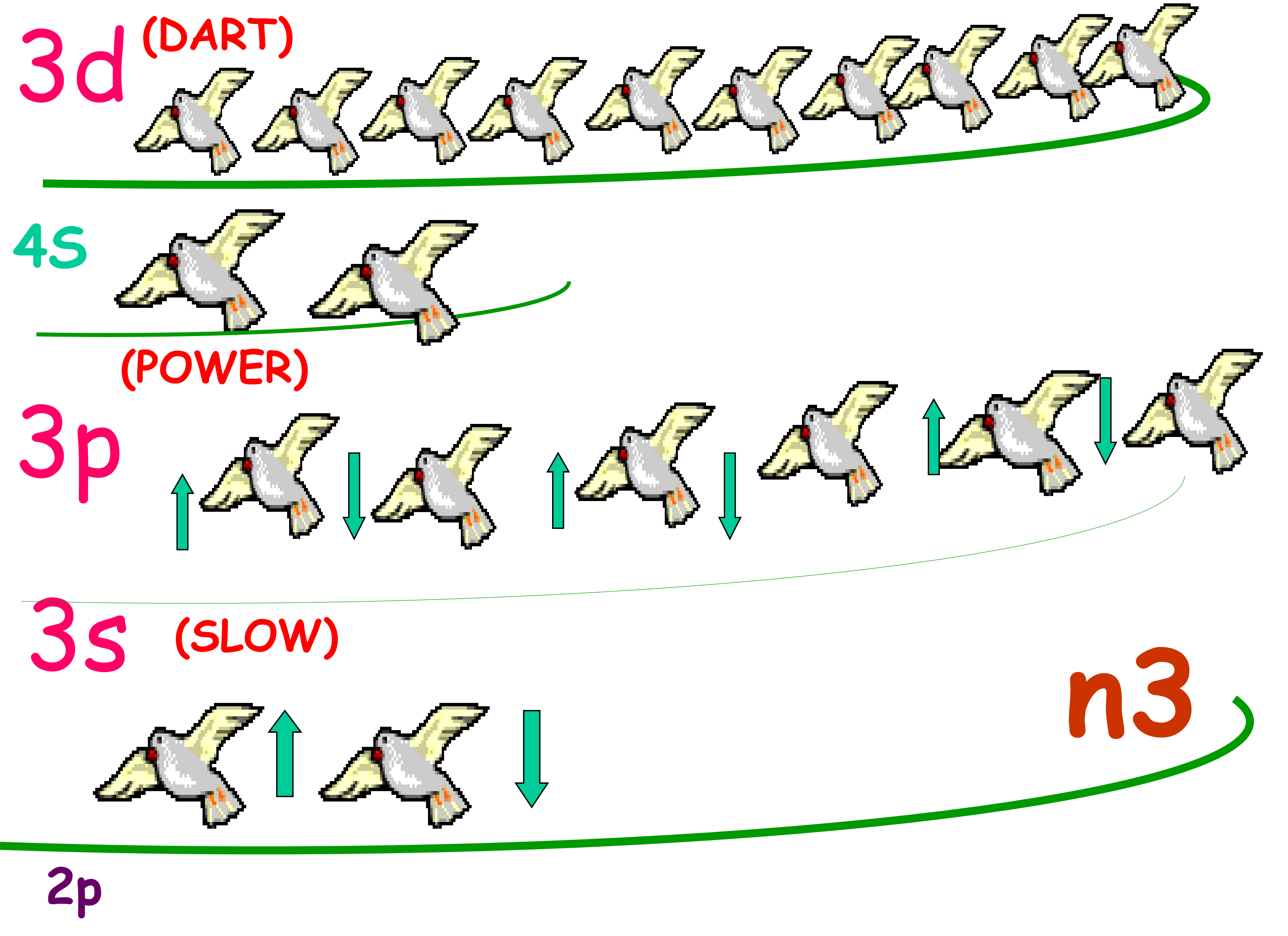
Birds → Electrons

n1 Branch → Principal Energy level

1s Spinning position → Energy sublevel

Opposite arrows show vertical spinning in the opposite directions


(POWER)
2p
2s
(SLOW)
n2
1s


3d
(DART)
4s
(POWER)
3p
3s
(SLOW)
n3
2p

Analog mapping

Create a table and ***guess*** the targets for the following analogs:

Analog	Target
Birds	Electrons
Branch	
Cage	
Spinning position	
Slow level	
Power level	
Dart level	
Fastest level	
A pair of birds	