School of Applied Sciences

Evaluation of a University Physics Studio Learning Environment: The Interrelationships of Students' Perceptions, Epistemological Beliefs and Cognitive Outcomes.

Shelley R. Yeo

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Abstract

Physics learning has been the focus of much research over the last few decades. One line of such research has had knowledge about physics conceptual understanding as its object. Conceptual physics learning is found to be enhanced by the use of a variety of interactive engagement teaching and learning strategies. Another line of research in physics education has been through the development of computer-based learning environments as alternatives to traditional lecturing approaches. One such development has been that of a 'physics Studio' in which computer software delivers content and facilitates activities and communication, and instructors adopt a tutoring or learning facilitator role rather than lecturing role.

Curtin University of Technology has drawn on both lines of research, resulting in the creation of a Physics Studio. In addition, a constructivist philosophy has provided guiding principles underpinning the conduct of first year physics classes. The aim of this study has been to evaluate students' physics learning in first year Studio classes. In particular, the aim has been to examine the role of students' epistemological beliefs (beliefs about knowledge and knowing) and their perceptions of the learning environment, in that learning.

The study is situated across the fields of psychology and physics education research. It uses an ex-post facto comparative research design together with a qualitative methodology to compare students in Studio classes with those in physics classes in a traditional lecture stream. The use of multidimensional scaling as a technique for reducing complex data to a visual form for the purpose of describing and investigating the Studio learning environment is also explored.

Findings from this study suggest that a Studio approach that incorporates student-centred, social constructivist teaching and learning behaviours can result in improved learning for students in a discipline such as physics, which is normally associated with authoritative and didactic teaching.

The results indicate that most students responded positively to the characteristics of the Studio approach. Their learning outcomes and improvement in conceptual understanding exceeded those of students in the traditional lecture classes. Students' beliefs about the structure of knowledge affected their cognitive

outcomes through their preference for particular learning strategies. Students with 'naïve', positivist epistemological beliefs were more likely to choose a narrow range of learning strategies and to have poorer cognitive outcomes. Students with more 'sophisticated', constructivist epistemological beliefs were more likely to choose a wider range of learning strategies and to have better cognitive outcomes.

There is evidence from this work that the constructivist learning environment influences students' epistemological beliefs, and that their beliefs influence the way they respond to the learning environment. Using multidimensional scaling, spatial configurations of learning environment parameters for Studio and traditional groups, although structurally similar, were visibly different. In particular, the *preferred* learning environment of Studio students formed a complex web of interrelationships, whereas the *preferred* learning environment of students in the traditional course formed a simpler pattern with minimal interrelationships among parameters.

Other factors affecting the responses of students to the constructivist learning environment were their perceptions of the nature of the subject matter as represented by assessment tasks, and their expectations about the role of instructors. Some students were unable to change their epistemological beliefs and learning patterns to fit teachers' expectations.

These findings have implications for teachers of physics who adopt or wish to adopt constructivist rather than didactic teaching methods, and for those implementing Studio approaches. An instructor's best efforts to implement alternative teaching approaches and methods can be circumvented by the beliefs and attitudes of students if they are inconsistent with the epistemology implicit in the teaching methods. For example, students with naïve beliefs in the structure and certainty of knowledge need guidance and experiences that provide validity for different ways of learning physics. Students also need help to understand the concept of, and to value, self-reflective learning practices. Finally, learning in a Studio class is enhanced for students whose beliefs are consistent with, or change to suit, the philosophy underpinning instruction.

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Abbreviations

Term or acronym	Meaning
CO	Cognitive outcome
CK	Certain Knowledge (epistemological belief dimension)
EA	Expert Authority (epistemological belief dimension)
EB	Epistemological belief
FA/QL	Fixed Ability/Quick Learning (epistemological belief dimension)
FMCE	Force and Motion Conceptual Evaluation
IE	Interactive engagement (teaching strategies)
IT	Information technology – meaning computers and related technologies used for all forms of communication.
LE	Learning environment – restricted to a classroom learning environment and not computer software.
Map	Spatial configuration of correlations among variables produced by multidimensional scaling
MDS	Multidimensional scaling
MPEX	Maryland Physics Expectations Survey
PW101	First semester physics unit – Particle and Waves 101
QEB	Questionnaire on Epistemological Beliefs
QM Test	Quantum Mechanics test
R	A symbol for dimensionality (see section on multidimensional scaling)
RMS	Root mean square
RPI	Rensselaer Polytechnic Institute
RSQ	Squared correlation between distances and disparities in a MDS solution. Represents the proportion of variance in the data accounted for by the MDS model.
SCR	Student opportunity for communication and reflection – a subgroup of scales on the USCLES
SI	Studio instruction 'matched' group
SK	Simple Knowledge (epistemological belief dimension)
SMARF	Self-monitoring and reflection form
SM102	Second semester physics unit – Structure of Matter 102
SSA	Smallest space analysis – a variant of non-metric multidimensional scaling
TCE	Thermal Concept Evaluation
TEE PHYS	Tertiary entrance physics examination
TER	Tertiary entrance rank
TI	Traditional instruction 'matched' group
TIQ	Teacher interpersonal qualities – a subgroup of scales on the USCLES
USCLES	University Social Constructivist Learning Environment Survey

Advice for readers

Chapter 4 is in two parts. Part B contains data analysis that is a precursor to Part A.
Appendix A 7.2 contains a data flow chart to facilitate tracking of data from source to where it is used.

CHAPTER 1: OVERVIEW OF THE STUDY

Many physics teachers, myself included, began teaching physics the way we were taught – with the focus on the physics content, not on the learners. For me, a turning point came when I reflected on the following incident: Three students were performing a routine pendulum experiment and were lagging behind the rest of the class. I watched and listened as they argued about their results when changing the mass of the pendulum bob. They had repeated the experiment three times but each time measured same period – 1.2 seconds. They were frustrated and perplexed. So certain were they that the period should change as the mass increased, they kept looking for a mistake in their technique or blaming their instrument (a stopwatch). Finally, one student remarked: "Physics is stupid." This was the first time I really understood the strength of students' beliefs and alternative physics conceptions, and how they could subvert any expository teaching.

1.1 Introduction

Education research within the physics education community has become increasingly vigorous over the last two decades. This growing interest can be traced back to emerging epistemologies and the rising popularity of constructivism as a theory of knowing. Constructivism has provided a fruitful means to explain and draw further attention to students' alternative knowledge frameworks in physics. With this came the development of techniques and instruments for assessing students' conceptual knowledge. Use of quantitative instruments such as the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992), as well as interpretive research methods, made it abundantly clear that students were learning to pass formal physics tests while retaining naïve and unproductive physics understandings (Duit, Goldberg & Niedderer, 1992; McDermott, 1984; Redish, 1994).

Physics educators and physics education researchers have subsequently designed teaching methods and strategies based on the results of research. Continual reassessment and revision was, and still is, being undertaken to gauge the effectiveness of such interventions. Other educators have re-designed whole physics courses or created innovative learning environments aimed at changing the way physics education is conceptualised and implemented – for both students and instructors.

One such learning environment, a Physics Studio (Wilson, 1994), was designed and began operation at Rensselaer Polytechnic Institute (RPI) in 1993. The Curtin University Physics Studio, which began in 1997, was modelled on the RPI Studio. Hence, it is appropriate that an evaluation of students' learning in the Curtin Physics Studio is conducted, in part, within the framework of other research conducted by the physics education community.

The progressive research programme in physics education is not embraced by all physics departments nor by all colleagues in departments involved in education research. There is a majority that adheres in its educational philosophy to the same positivist paradigm within which the physics community conducts its everyday research. Such a philosophy acknowledges that problems which students have in learning physics stem not from students' inadequate conceptual frameworks, but rather from the difficulty of the subject or students' lack of effort or ability (Ernest, 1995). Indeed, unless teachers adopt and interpret their role from within a more constructivist philosophical position, much of the effort at changing teaching methods and strategies will appear to be for little or no reward.

In this chapter, I will outline the history and development of the Studio model of physics instruction and frame the objectives and specific research questions for this study. I will then describe in detail the Curtin Physics Studio, the two relevant physics units that the students undertook, the students involved, and contrast them with the arrangements for students involved in equivalent lecture-based physics units.

1.2 Physics instruction at Curtin University of Technology

This particular study concerns the experiences of first year students learning physics at Curtin University in a classroom setting and instructional format that are non-traditional. Traditionally, physics has been taught through a combination of lectures, problem-solving tutorials and laboratory sessions. The lectures have been didactic with few, if any, demonstrations and tutorials have been for the purpose of 'going through' assignment questions.

In 1996, following a three-day workshop given by Professor Jack Wilson from Rensselaer Polytechnic Institute, Dr R. Loss from the Department of Applied Physics and Mr D. Thornton from the Computing Centre established the Curtin Physics Studio, which heralded a new approach to instruction in this Physics Department. Physics instructors, thus freed of the constraints imposed by 'traditionalist' expectations began adopting a variety of innovative, experimental, research-based or personalised approaches to teaching physics.

A major question that has ensued is: Are these approaches better than the traditional, and arguably more cost-effective, lecture method? Anecdotal evidence and class surveys suggest that many students prefer the different teaching approaches and respond favourably to class work integrated with computer-based activities (Loss & Thornton, 1997, 1998). But, does the 'feel good' or novel aspect of the Studio equate to improved learning outcomes? What do they learn in the Studio that they do not learn in the traditional lecturing situation? What do they not learn? Do students learn differently in this environment? If students, through their prior physics education experiences, have a particular view of physics, particular beliefs about knowledge or have come to expect physics to be taught in particular ways, will the Studio approach make them less or more able to engage in effective learning? Will their approaches to learning change in response to the different mode of instruction? Such questions are difficult to answer, and are certainly not answered by casual surveys.

This study is an evaluation of students' learning in a particular Studio-based physics course from the perspective of students' perceptions of their learning environment and their beliefs about knowledge. It cannot be an evaluation of the Studio per se because there is no definitive 'studio method' and different teachers teach in different ways. Instead, it evaluates learning in a Studio-based learning environment that is guided by research into physics learning, conceptual change learning and self-directed learning, and informed by principles underpinning a social constructivist philosophy.

Although the physical setting, facilities and many activities are common to a general Studio approach, other factors make the Curtin University Studio learning environments somewhat unique. A learning environment is:

> *…a composite of constituent factors including: physical setting, a set of agreed behaviours, consensual expectations and understandings, particular tasks around pre-specified contents for explicitly-stated goals that are guided by a person who has been given the responsibility over that setting, its participants and activities.*
>
> (Salomon, 1996, p. 365)

Thus the evaluation of a learning environment can only be for a particular group with its particular teachers.

Patton (1990) describes evaluation research in the following way:

> *When one examines and judges accomplishments and effectiveness, one is engaged in evaluation. When this examination of effectiveness is conducted systematically and empirically through careful data collection and thoughtful analysis, one is engaged in evaluation research.* (p. 11)

Hence, this study is a systematic examination of the accomplishments and effectiveness of a particular Studio course.

There is no absolute standard against which assessment of the Studio course can be judged. The only basis for comparison is what has traditionally existed – the lecture/tutorial method. This is the norm. A reasonable way of evaluating the students' learning in a Studio course is to compare it with the learning of students' in a traditional course teaching the same content. The existence of such a comparable group of students on the same campus has made an Ex-Post Facto comparative research design (Crowl, 1989) possible, and indeed, reasonable. The research questions, however, centre not on whether one group is superior to the other, but in what respects the two groups are the same and in what respects they are different, and if so, how are they different?

1.3 Overarching questions

This study primarily aims to evaluate Studio course students' learning by comparing it with the learning of students in a subject with the same physics content but taught in the traditional mode. This is translated into the following overarching questions:

1. What are the cognitive outcomes of students learning physics in the Studio course?
2. How do these students assess and respond to the social constructivist nature of their learning environment?
3. What is the nature of the interrelationships among students' perceptions of the learning environment, epistemological beliefs and cognitive outcomes?
4. How can these interrelationships be made explicit or understandable?

Part of the problem being investigated is whether or not there are identifiably different experienced learning environments, Studio versus Traditional, or is the experience of learning physics at the First Year university level determined by the subject and other constraints to the extent that different instructional modes or settings are irrelevant.

1.4 Specific research questions

1. What are Studio students' learning outcomes?
   a. Do students in the Studio course out-perform those in the traditional course as measured by common assessment instruments?
   b. Do students in the Studio course out-perform those in the traditional course as measured by concept-testing instruments?
   c. Do students develop skills and confidence in using computers?
2. What roles do Studio students' perceptions of their learning environment play in their physics learning?
   a. What are Studio students' perceptions of their actual and preferred learning environment, and how are they different from those of students in the traditional course?
   b. Are Studio students' perceptions of their learning environment related to their physics learning outcomes?
   c. Do Studio students apply self-reflection skills?
3. What roles do Studio students' epistemological beliefs play in their physics learning?
   a. What are students' initial epistemological beliefs?
   b. Are students' epistemological beliefs related to their physics learning outcomes?

c. Are students' epistemological beliefs related to their perceptions of the learning environment?

d. Does participation in the Studio course change students' epistemological beliefs?

e. What study methods/processes do students favour?

4. Can multidimensional scaling techniques be used to represent and differentiate between the Studio and Traditional learning environments?

1.5 Multidimensional scaling

In Chapter 5 I use multidimensional scaling (MDS) to produce visual representations of the two physics learning environments. MDS refers to a family of data analysis methods that can portray the hidden structure within the data in a spatial pattern that is visually interpretable. The basic assumption of an analysis using an MDS model is that it is easier to look at a picture of the data than to look at the data themselves. It relies on the fact that humans are very sophisticated when it comes to understanding the characteristics of Euclidean space.

The use of MDS in representing learning environments is comparatively new and not well refined. The technique was originally used in psychology but, more recently, social sciences have found it increasingly useful in making visual sense of a large amount of numerical data. Two studies that report using MDS for the study of educational environments and learning are Salomon (1996) and Bar-On and Perlberg (1985).

MDS is being used here in an exploratory way. I use it to:

- Produce 'maps' to characterise the learning environment from the students' perspective.
- Compare the information provided by the maps with that furnished by the other comparative analyses of the same data.
- Compare the learning environments of the two student groups through an examination of pairs of maps; and
- Comment on the use, and potential use, of the technique for representing learning environments.

1.6 Constructivism in education

As I shall argue later that the approach to teaching in this Studio course is best described as 'constructivist' or 'social constructivist'. The following is a concise contemporary statement of what constructivism in education means. It has been drawn from Fosnot (1996).

Constructivism is a theory about knowledge and learning. It describes both what "knowing" is and how one "comes to know." Learning is thus viewed as a self-regulatory process of rationalising between existing personal models of the world and discrepant new insights, and constructing new representations and models of reality.

Teachers who base their practice on constructivism reject the idea that learners can incorporate exact copies of teachers' understanding for their own use. A constructivist view of learning suggests an approach to teaching that gives learners the opportunity for concrete, contextually meaningful experience through which they can search for patterns, raise their own questions and construct their own models, concepts and strategies.

The classroom is a community of learners engaged in activity, discourse and reflection. The traditional hierarchy of teacher as the autocratic 'knower' and learner as the unknowing controlled subject studying to learn what the teacher 'knows' begins to dissipate as teachers assume more of a facilitator's role and learners take on more of the ownership of the ideas.

1.7 Epistemological beliefs

> *Epistemological beliefs are beliefs that people have about knowledge and knowing – what knowledge is, and what it means to know and to build knowledge. Epistemological beliefs are thought to affect the way that students understand the learning process (Bendixen, Dunkle & Schraw, 1994; Hammer, 1994; Perry, 1970; Schommer, Crouse & Rhodes, 1992).*

Hofer and Pintrich (1997) outline some of the issues regarding students' epistemological theories:

> *Students' theories about knowledge may be activated by a variety of tasks. These theories then influence how individuals approach these tasks in terms of their motivation and cognition. It is also plausible that the structure of these academic tasks, over time, shapes*

> *epistemological theories, which are then difficult to change. For example, students who are given multiple choice tests composed of low-level items may come to view knowledge as a collection of facts and learn to study for tests by memorisation and rehearsal strategies. Moving to a class where higher-level processes are expected may require not only a change of learning strategies but also a change in the students' epistemological theories. We know little about the malleability of epistemological theories or the discordance students may experience between their theories and the type of classroom environments and tasks they encounter* (p. 128).

Thus, it might be expected that students' epistemological theories or beliefs will affect how they respond to a Studio learning environment. It is also plausible that students' Studio experiences will affect their epistemological beliefs.

1.8 Research on student learning in higher education

Student learning in higher education is on the boundary of two disciplines – education and cognitive psychology – but in an area of overlap, not fully within the core of either (Richardson, 1987). Problems of combining psychology and education result from the different goals and pursuits of the two fields of research. For example, cognitive psychology:

1. Develops theories about the processes and mechanisms that are common to all individuals, and has little interest in studying differences between individuals. It tends to ignore changes occurring within individuals over time.
2. Is interested in evidence of a behavioural nature that can be represented in quantifiable terms. It is not interested in the nature of experience because it is seen as subjective. Hence the research paradigm is primarily scientific, not phenomenological.
3. Reports studies that have little 'real world' relevance i.e. little ecological validity.

Research in education tends to be the opposite of that above:

1. The main focus is on differences among individual learners, and hence lacks a well-articulated general theory of human learning.
2. Learning is a human capacity, but only recently has educational research been more sensitive to the experiential aspects of cognition i.e. personal, subjective accounts.

3. Research on learning in secondary education has been assumed equally valid when applied to higher education.

Most research work on learning in higher education has been located in natural settings (naturalistic), descriptive and easier to relate to real-life, but also lacking in explanatory content. This study attempts to combine both principles of psychological research and methods of education research to understanding how students learn physics in a particular tertiary learning environment.

The review of literature (Chapter 2) suggests that factors affecting students' learning are their prior knowledge and their learning 'resources', i.e. their psychological dispositions and attitudes, and preferred learning behaviours. I propose that these have the structure illustrated in Figure 1.1, whereby cognitive outcomes serve to confirm or modify students' learning resources.

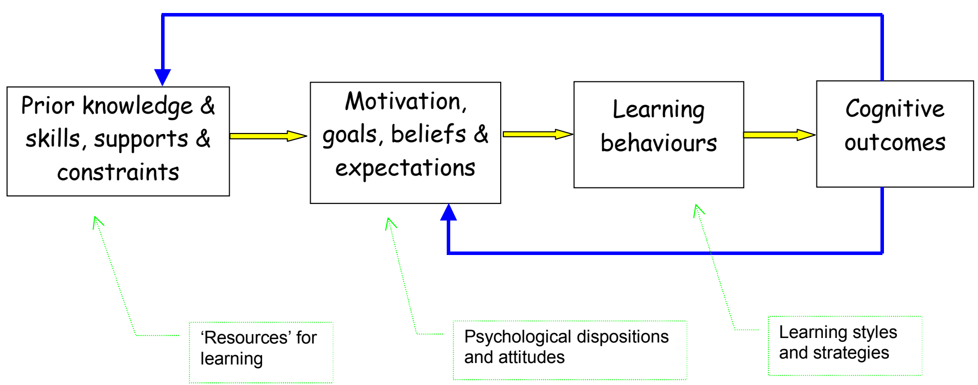


Figure 1.1. A proposed model of links between factors that affect learning.

This study focuses on certain aspects of the group of psychological dispositions and how they influence or are influenced by learning behaviours and cognitive outcomes for students learning physics in the Studio. See Figure 1.2.

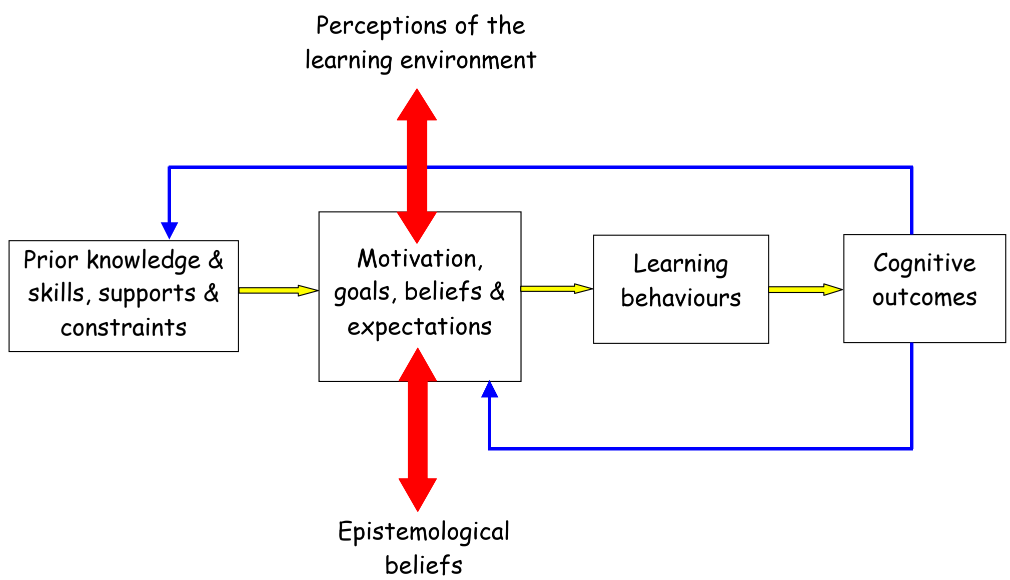


Figure 1.2. Variations to Figure 1.1, on which the unique aspects of this study are superimposed. I propose that epistemological beliefs and students' perception of their learning environment affect their learning behaviour and thus will impact on cognitive outcomes.

1.9 Development of the Studio model of instruction

The Studio concept was the brainchild of Professor Jack Wilson at Rensselaer Polytechnic Institute (RPI) in 1993. Working on the idea of an artist's studio, Wilson developed a Studio classroom equipped to facilitate courses in which student-centred, interactive, technology-supported classes replaced more traditional forms of physics instruction.

The initial goals for operation of the RPI Studio (Wilson, 1994) were to:

- reduce student contact hours;
- maintain or improve learning outcomes;
- increase instructor and student satisfaction; and
- improve student attendance rates.

A further goal, more implicit than explicit, was to enable students, through their everyday activities, to model the work of practising physicists in an information technology rich environment.

Wilson (1994) argues that the maintenance of a traditional lecture method of course delivery, despite clear demonstrations that it is ineffective for many students, rests on three rationales:

1. Lectures *can* be an educationally effective method of teaching.
2. Although the lecture is usually ineffective, *outstanding* lecturers can turn the lecture into an effective learning environment.
3. The traditional course is the most *cost-effective* way to educate hundreds or thousands of students per semester.

Wilson was working on the premise that, with the continued development of computers and software, information technology (IT) would be able to provide instruction at least as effectively as, if not better than, traditional didactic lecturing, laboratory and tutorial sessions. A suite of computer programs called the Comprehensive Unified Physics Learning Environment (CUPLE) (Wilson & Redish, 1992a, 1992b) was developed to facilitate delivery of content and enable integration of laboratory-based activities with problem-solving work. Wilson believed that computers could deliver a significant proportion of the instruction to students both in set instructional periods and in students' own time, enabling the lecturer and assistant to be able to spend more time helping students individually through a process of Socratic dialogue. Reducing students' formal instruction time from six hours of lecture, laboratory and recitation to four hours of combined instruction offset the cost of equipping the specially designed rooms with computers and other equipment.

1.9.1 Studio as a metaphor

The Studio metaphor conjures a vision of a creative environment in which students are *actively* involved in constructing understanding. It embraces the cognitive apprenticeship model of situated cognition (Brown, Collins & Duguid, 1989) in which experts and novices collaborate in completing tasks, with one providing the other with guidance at an appropriate level. It was believed that this would demonstrate a commitment of physics teaching staff to changing and improving the educational experience of their students as well as reflecting evolving changes in teaching and learning. It was also felt that the Studio metaphor better represented the collaborative and technology-focussed nature of the work of physicists (Loss & Thornton, 1997).

1.9.2 Rensselaer Polytechnic Institute Studio evaluation

Cooper (1995) evaluated one semester of operation of a RPI Physics Studio course. She measured students' conceptual understanding of physics using the Force and Motion Conceptual Evaluation (Thornton & Sokoloff, 1998), the Force Concept Inventory (Hestenes et al., 1992) and various problem-solving exercises. Through observation, interviews with students about their perceptions of the Studio and details of academic progress, Cooper was able to document changes over the semester. Of particular relevance to this study are the outcomes of Cooper's evaluation:

- The conceptual knowledge gains of students in the course were equivalent to those made by students in a good traditional course.
- The conceptual knowledge gains made by students were less than those recorded by students using the microcomputer-based laboratories at Tufts University.
- Students showed little improvement in either problem-solving skills or in the quality of their explanations.

Cooper's research methodology was weakened by late changes to the RPI physics course organization, which altered what she had initially planned to evaluate. She was unable to make use of a parallel lecture stream intended for use as a control. As well, because of time constraints and differing beliefs and skills of particular instructors, the course that was actually studied differed from that which was portrayed in the planning stages. As a result, she felt that she did not evaluate an 'ideal' studio course, but rather, one that had been interpreted and implemented by different instructors.

> *The modification of the course by instructors, and the outcomes concurrent with those modifications, indicate that the results of using the course may be dependent on the educational beliefs of instructors as those beliefs are evidenced in their implementation of the Studio format.*
>
> (Cooper, 1995, p. 110).

It is apparent, therefore, that many factors and constraints combine to produce an 'implemented' Studio course, where the implemented curriculum may be different from the designed one. The instructors' beliefs, motivations and pedagogical philosophy may be significant factors influencing the teaching strategies adopted and hence students' learning outcomes. Loss and Thornton (1998) independently drew a similar conclusion about the Curtin Physics Studio, whereby the learning environment and students' outcomes were thought to be influenced more by the teacher than by the Studio facilities.

The Studio physics course at RPI has undergone change as a result of Cooper's earlier evaluation and because physics education research is increasingly supporting the effectiveness of recognised interactive engagement programmes. Cummings, Marx, Thornton and Kuhl (1999) have reported a study in which they examined the differences between Studio classes employing different instructional strategies. Seven standard first year classes, with four different instructors, were taught by the regular Studio method. Five 'experimental' classes were offered a Studio programme which had been modified to incorporate either or both of Interactive Lecture Demonstrations (ILDs) (Sokoloff & Thornton, 1997) and Cooperative Group Problem Solving (CGPS) (Heller, Keith & Anderson, 1992, cited in Cummings et al (1999)). The primary data sources were the students' pretest and posttest results on the FCI and FMCE, and the results interpreted in two ways. The value <g>, or *average normalised gain*, (Hake, 1998) was calculated for each group. There is further discussion of this statistic in Section 4.2.1. The researchers also detailed some of the problems associated with implementing ILD and CGPS strategies, some of which were as a result of the instructors' inexperience with the techniques.

> ***Conclusions derived from the Cummings et al study were:***
> The standard classes, taught through current interpretations of the original Studio course, achieved average normalised gains that were no different from those measured by Cooper in 1995. See Table 1.1. The authors suggest that the activities used in the standard Studio classes are, in fact, no more than traditional activities adapted to fit the Studio environment and incorporate the use of computers, and furthermore, that interactivity does not automatically signify that students are learning physics effectively.
>
> All 'experimental' classes achieved higher fractional gains than standard classes, suggesting that incorporating the more recognised instructional strategies of ILDs and CGPS into the standard Studio programme results in more effective physics learning.

All students, regardless of their pretest result, benefited from the experimental methods.

Table 1.1. Average normalised pretest-posttest gains from Cooper's 1995 RPI study, and Cummings et al's 1999 study of physics learning at RPI

	Average normalised gain	
Classes	FCI	FMCE
1995 – traditional classes	0.22	
1999 – traditional classes	0.18 ± 0.12 (s.d.)	0.21 ± 0.05 (s.d.)
1999 – experimental classes (ILD)	0.35 ± 0.06 (s.d.)	0.45 ± 0.03 (s.d.)
1999 – experimental classes (CGPS)	0.36	0.36

1.9.3 Other Studio physics courses

One other physics Studio course, developed at California Polytechnic Institute at San Luis Obispo during 1996/7 (Mottman, 1999), apparently suffered problems related to staff changes, funding constraints, inexperienced instructors and an unsupportive faculty (Kolitch, 1999). To date, no formal evaluation has been published.

There are developing Studio courses at other universities. One commenced operation at the University of South Australia in 1999, one at Kansas State University, and one at the University of Hong Kong. No further information about these courses was available other than public information on websites.

1.9.4 Curtin University Physics Studio

The Curtin Physics Studio began formal operation in 1997 with four, first-year physics units and a maximum of 24 students per class. In 1999, the space and facilities were expanded to accommodate 36 students per class. Although many features of the original, planned Studio programme are in place, there have been a number of modifications resulting in a divergence between the planned and implemented Studio programmes.

The CUPLE materials have not been effectively utilised, partly because of computer networking difficulties and partly because of growing uncertainty about the instructional effectiveness of interactive multimedia in teaching physics concepts (Yeo, Zadnik, Treagust, Loss & Harrison, 2000). Various other computer-based materials, teaching strategies and IT tools have instead been incorporated into the programme.

A compounding factor has been that various physics instructors have shown mixed responses to implementing the ideal, student-centred programme, often feeling under pressure to "get through the content" thereby reverting to "chalk and talk" when time is tight (Loss & Thornton, 1998).

1.10 Evaluating innovative teaching initiatives

Different perspectives for evaluating the effectiveness of innovative instructional programmes are from the viewpoints of the stakeholders – the students, the teachers, the teaching department and the university. Each of these will ask different questions. The students may well ask 'why us', and seek assurance that they will not be disadvantaged by being part of an 'experiment'. Teachers might ask about students' learning outcomes, demands on time and resources, the effectiveness of different initiatives, and about the experiences and involvement of students in the teaching/learning process. The Department and the University faculty may ask about cost effectiveness, retention rates, seek assurance that the curriculum is being faithfully 'delivered' and that standards are being maintained or improved.

Each of these is a valid question but they do not necessarily tell the whole story. I suggest that, as educators, the teachers should be asking such questions as:

1. What philosophy of knowledge and learning do they hold or adhere to (if at all)? How does this impact on Studio operation?
2. What assumptions are made about how students learn?
3. What assumptions are made about students' prior knowledge and skills?
4. What teaching strategies are being employed and what is the research basis of their effectiveness?
5. What are students' individual and shared perceptions of the learning environment and how do they relate to their learning environment preferences?
6. What are teachers' perceptions of the learning environment and how do they relate to students' perceptions of the learning environment?

7. What psychological traits and attitudes do students bring with them? Are any necessary for students' success? Do any work against students' success?
8. What cognitive, psychological and behavioural changes take place in students during and as a result of their Studio experiences?

At the time of starting this study, a number of analyses of the Curtin Physics Studio had been undertaken. On-going evaluation included surveys of student conceptual understanding of selected physics topics, expectations, attitudes to and use of the computing facilities, and cost-benefit analyses. Students' use of email was also monitored. The outcomes reported were positive student attitudes, increased student attendance (in relation to lecture attendance) and opportunities for the development of life skills and co-operative learning (Loss & Thornton, 1998). There has, however, been no formal evaluation of the Studio experience from the point of view of its participants nor any attempt to answer many questions which educators might ask.

Establishing the parameters of an evaluation is not an easy task (Patton, 1986, 1990). To start with, what is designed, i.e. the ideal course with design based on sound, researched pedagogical principles, may not be what is actually implemented or experienced. The questions asked may be designed to serve a limited range of purposes and hence, answers will paint a narrow picture. A further issue relates to the source of information, i.e. of whom are the questions asked? The perspectives of different stakeholders may provide different answers to the same questions. There may be no common basis for comparison, by which any measure of course/learning effectiveness can be given commonly understood meaning. Finally, the value of the experience for one student or teacher or department may be quite different from others' experiences.

Hence, while the concept of a technology-based Studio may encapsulate a physical setting and a suggest a metaphor for its operation and involvement between participants, there is nothing to suggest that it will actually operate or be perceived to operate as planned. Any evaluation must include ways of describing and interpreting the situation that is perceived to exist, and it should be done from the perspective of all participants.

1.11 Curtin University Physics Studio

The study that was undertaken centres on a particular Studio course, three instructors and two classes of students. Apart from the physical layout of the Studio, what is described below is limited to Studio operation for the designated courses, teachers and students only.

1.11.1 Physical layout of the Studio

The air-conditioned room has 20 PC computers and 40 swivel chairs on castered wheels. The swivel chairs enable two pairs of students to rotate and form groups of two or four without having to physically move the chairs. The networked computers have internet access and each student has space on the server to store temporary files or documents. All students have university- allocated email addresses.

At one end of the room is an instructor computer that runs the computer screen projector. There is a clear space in the middle of the room, which can be used for demonstrations or centrally focussed teaching strategies.

1.11.2 Units and unit content

The first year students involved in this study undertake two calculus-based physics units. Particles and Waves 101 (PW101), is studied in Semester 1 and Structure of Matter 102 (SM101), is studied in Semester 2. The unit content is shown in Table 1.2. The Unit Outlines can be found in Appendix A.2.2.

Table 1.2. Physics content of the two first year physics units that are the subject of the study.

Particles and Waves 101 (PW101)	**Structure of Matter 102 (SM102)**
Linear and rotational mechanics	Thermodynamics
Simple Harmonic motion	Quantum Mechanics
Wave motion and optics	Relativity

The units are mandatory for students studying for undergraduate degrees in Physics, Geophysics, Physics combined with either Computer Science or Electronic Engineering in double degree programmes and optional for those studying Multidisciplinary Science.

There are two other significant calculus-based physics units that most (but not all) students undertake concurrently with PW101 and SM102. Physical Measurements 101 is conducted in Semester 1 and Physical Measurements 102 in Semester 2. These units include Electricity and Electromagnetism and contain the formal experimental (practical) component of the first year physics course. Although these two units are also taught in the Studio they have a different instructor team and so are not included in this study.

Students attend the Studio for a three-hour time block in Semester 1 (for PW101) and for a two-hour time-block in Semester 2 (for SM102). The middle hour of the three-hour session is allocated to computer-based work, such as interactive problem solving or use of spreadsheets, so that students with less adequate skills can get additional help. It is assumed that such assistance is no longer needed in Semester 2. There is a break of about 20 minutes during the three-hour sessions but a much shorter break in the two-hour sessions.

NB: A one-hour time-slot is effectively 50 minutes of contact time.

1.11.3 Studio students

Most of the students enter their courses directly from high school and hence are aged 17-18 years. Some students transfer from other courses, while a few have worked for several years before undertaking further study. There are also a few mature-aged students returning to study, planning for career moves. A small proportion of students is from overseas – generally south-east Asia. Male students outnumber female students by about seven to one. Demographic data for all students will be outlined in Chapter 4.

1.12 Curtin University lecture-based physics course

Traditional course organisation

Students in various Engineering undergraduate degree programmes undertake one or both of the physics units PW101 and SM102. These students are offered the lecture-tutorial course only, conducted in 200-300-seat lecture theatres. They attend two one-hour lectures and one one-hour tutorial per week. There are 150-180 students in the lecture theatre and 15-25 students per tutorial group. The tutor is required to review the week's assignment that students have handed in for marking and provide help for students as required.

Units and unit content

The syllabus for the lecture-based PW101 unit is identical to the Studio-based unit. Despite having the same unit title and number, however, SM102 has a component on Geometric Optics instead of the Thermodynamics component that Studio students study.

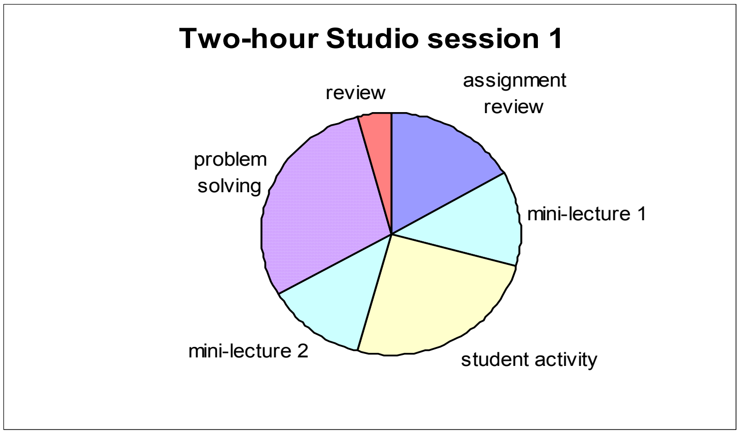
Students in lecture course

Engineering undergraduate students are similar in age and background to the Studio students but with a greater proportion of overseas students and lower proportion of mature age students.

1.13 Studio method under study

A Studio session has no mandated structure. The specific physics content and activities are confirmed at a weekly planning meeting several days prior to each session. There is a set course outline and nominal semester programme, but flexibility is maintained so that the instructor team can adapt each session to the needs of students and in response to problematic situations as they arise. For example, if students have experienced difficulty with a section of the work, a short revision segment may be planned, or if a new or revised activity is deemed necessary, it may be developed during the semester. Two typical Studio session plans are shown in Figure 1.4.

Students are required to complete a set amount of homework each week. They are given approximately four problems to solve, to be handed in for marking one day prior to the subsequent Studio session. The assignments are marked by one of the instructor team, generally the tutor, and returned to students just prior to the start of the session. They form the basis of the assignment review. See Figure 1.3. The purpose of the review is not to re-work each problem, but to alert students to common errors or misunderstandings and/or to review problem-solving techniques. Fully worked solutions are posted on a notice board.



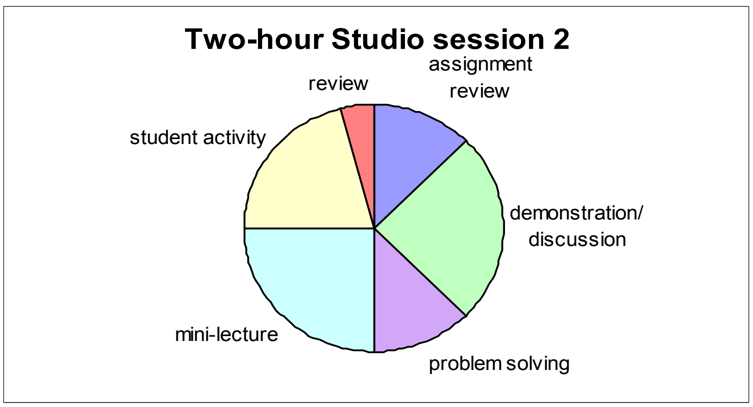


Figure 1.3. Two depictions of typical Studio instructional sessions. The session starts at the top in each diagram. If in a three-hour format, the middle 'hour' is a computer skills-based activity closely related to course content.

In addition to the assignment problems, students are also advised of the book sections to be summarised prior to the next class. This alerts them to the physics content that will be covered the following week. Marks are allocated to students for the satisfactory completion of both of these tasks.

The instructional team collaboratively constructs the mid-Semester tests and the Semester exams.

Teaching team

Cooper (1995) noted that the RPI Studio course was shaped by the individual instructors through their beliefs and motivations, and the constraints under which they were working. It is a reasonable to propose that the Studio course that is the subject of this study is also defined and shaped by the members of the teaching team and that a unit/course with a different teachers will not be the same. I will therefore provide a brief overview of the skills and experience of the Studio teachers in this study.

Teacher 1

Experienced Senior Lecturer within the Department of Applied Physics.

Strong commitment to helping students set personal achievement goals and taking responsibility for their own learning.

Advocate of collaborative learning and mutual support in the learning process.

Commitment to physics education reform.

Teacher 2

Skilled post-doctoral researcher.

Some lecturing and tutoring experience.

No professional background in educational philosophy or pedagogy.

New to the Studio experience.

Teacher 3

Experienced physics educator at secondary level.

One year's experience in the Studio in the role of tutor.

Recent research experience in science education and learning physics with computers.

Teaching philosophy

It cannot be claimed that a single philosophical stance was adopted, nor a single set of strategies used in teaching. However, the following beliefs about learning have shaped the particular course structure that is evaluated in this study.

Students must learn to accept responsibility for, and monitor, their own learning. We do not expect students to be able to do this immediately, but the guidance and support provided at the start of Semester 1 is gradually decreased over the course of the year.

Learning is an individual as well as a community activity. While it is impressed on students that their learning will be judged individually (i.e. using tests and examinations), they are strongly encouraged to form study groups to help one another through discussion and analysis of each other's work output.

1.13.1 Details of the Studio physics course

Syllabus

There is a formal, agreed syllabus, determined by the Department of Applied Physics. However, the teaching team must interpret the syllabus and its physics content.

The teaching team has determined that the textbook (Serway, 1998) defines the physics content that students are to learn. We emphasise to students that they are expected to come to an understanding of the physics ideas that are represented in text, mathematical symbols, diagrams, graphs and other representations.

Source of physics knowledge

Physics knowledge is portrayed to students as understandings of the scientific or physics community, developed though the endeavours of both famous physicists and through the work of countless other researchers.

Lesson plans

There is a weekly meeting prior to the Studio class at which the conduct of the lesson is planned. Through consensus we determine the likely range of prior understandings of students, pedagogical strategies and student activities. Mini-lectures and student activities focus on the most important or difficult concepts. Knowledge of research and personal experience inform this aspect of planning. This implies that some concepts may not be dealt with at all in class.

Teaching strategies

The instructional strategies are drawn from a variety of sources. Some, such as Active Lecture Demonstrations (Sokoloff & Thornton, 1997) and Peer Instruction (Mazur, 1997), are collectively known by the Physics Education Research (PER) community as 'interactive engagement' strategies. Others are developed from internet and other computer-based resources or are our own resources. See Chapter 3 for a more detailed discussion of research-based physics instructional materials and strategies.

Physics is about the physical world and how physicists organise their knowledge of the world. Students are familiar with only a small part of this world and so emphasis is given in classroom examples and illustrations, or in homework problems, to focus or start with the students' experienced world before progressing to more abstract ideas.

Our beliefs about teaching and learning, and the importance that we attach to our various instructional strategies are conveyed to students explicitly and the ideas reinforced through constant reminders of the role that is expected of students in the process.

Student responsibilities

Students are responsible for their own written materials. We require them to make their own *summaries* (or other personal representations) of the physics in each relevant chapter of the text book prior to the week in which that chapter or physics content is dealt with in class. We do not give lecture notes, nor do we assume that students will make cohesive notes during the various class activities. Instead, students are asked to bring a file or notebook in which to keep jottings, ideas, solutions to class-based problems or outcomes of practical activities. They are required to maintain a *portfolio* and/or electronic copy of all their work over the semester. Marks are allocated for satisfactory completion of this task.

Students are encouraged to adopt metacognitive strategies in thinking about their own learning and understanding of physics and how they present their understandings in written work. Students are given weekly reminders of where they should be with respect to their reading, learning and summaries, homework to be done and related, optional activities and resources. They are challenged to see their work as if through 'other eyes' and to consider how they would like to be ultimately judged by employers, colleagues and themselves as professionals.

Personal goal setting and the evaluation of the achievement of their goals are made explicit to students through the formal *Self-Monitoring and Evaluation Form* (SMARF). See Appendix A.1.8. There are also occasional reminders to students to keep up the self-evaluation process. Marks are allocated for satisfactorily completing this process.

Social aspects of learning

Collaborative and social learning are given emphasis in class and also expected of students outside class hours. This is achieved through asking and receiving questions, student-student or students-teacher discussion and problem solving and encouragement to help one another with assignment questions and other learning difficulties outside of formal class hours. The instructor team is considered part of this out-of-hours process.

Students are instructed to work on computer-based tasks in pairs. Some are reluctant to do this but research has suggested that this results in better learning outcomes for students learning physics (Yeo, Loss, Zadnik & Treagust, 1998).

Assessment

The teaching team works within an assessment and examination procedure, mandated by the University and enforced by the Department of Applied Physics.

Assessment details

Examination	50%
Tests (2)	20%
Assignments	20%
Summaries	7%
Workbook and SMARF	3%

Note: The lecture course does not have the final two categories, and allocates that 10% to the exam and/or tests.

The mid-semester tests and end of semester examinations are traditional in format. Most of the questions are multiple-choice, although these include qualitative and quantitative types. Most questions expect students to connect two concepts to be able to determine an appropriate answer or response. In other words, the questions are not easier through being multiple-choice in structure. The decision to conduct most assessment in this way is more through expediency than philosophical commitment to the design of such tests. There is also a Departmental expectation that some, if not all of the examination will be common with the lecture stream courses to maintain a degree of comparability.

In Table 1.3 is a comparison summary for the two types of instruction, Traditional (TI) versus Studio (SI):

Table 1.3 A comparison of traditional and Studio instructional methods.

Traditional instruction	**Studio instruction**
Separate lectures and tutorials. Tutor is likely to be different from lecturer. Both work from the front of the lecture theatre/room. Tutors get to 'know' the students.	Integrated lecture, tutorial, laboratory and/or computer-based activities. Two instructors (one is nominally a 'tutor' or teaching assistant) attend class simultaneously, 'know' the students and move among them during the lesson.
Lesson content is determined by the syllabus so that relevant physics concepts and content are covered in a traditional, logically coherent way.	Lesson content is determined by key or difficult concepts. No attempt is made to cover content – students are expected to 'fill in the gaps' through their own reading/summarising of text material.
Students attend lectures, write their own notes and have access to copies of lecture notes.	There are no formal lectures, no lecture notes given, nor are students expected to write anything more than their own ideas or reminders.
Demonstrations, if performed, are illustrative and teacher-directed.	Demonstrations are interactive, students' ideas are explored through discussion, and meaning is developed consensually.
Assessment incorporates traditional examinations, tests (calculation and concept questions) and assignments (calculation).	Assessment incorporates traditional examinations, tests (calculation and concept questions), assignments (calculation), summaries of text material, maintenance of a portfolio with on-going self-reflection and monitoring exercise.
Students are given full responsibility for their own learning.	Responsibility for students' learning is initially shared – but transferred to students over the year.
	Informal, collaborative learning is encouraged.

1.13.2 The Studio in operation

I would like to invite the reader to enter the Studio with me for a brief visit during a first year physics lesson. The Studio is not a large room about 8 x 15 metres. There are two instructors, nominally a 'lecturer' and a 'tutor' (or teaching assistant) together with about 30 first year physics students. There is a continual buzz of conversation but the activity appears coordinated.

Students are seated in pairs in front of their computers whose screens display animated physics problems that the students are solving. They must analyse each physical situation and manipulate the diagrams to gain the information they think they need to solve the problem. The information is not simply presented to them.

The students are drawing on many cognitive resources: thinking, discussing and questioning. They swivel around in their chairs to the pair behind to compare strategies and seek alternative viewpoints then return to investigate another avenue. Some students are ahead – they have submitted their answers electronically and are considering their responses against the feedback provided. Others are struggling to make a breakthrough in their reasoning. The two instructors move from pair to pair, helping, questioning or concurring. The teachers don't profess to 'know all the answers' but instead try to take a more equal investigative or problem-solving role with students.

We now move to later in the lesson. One instructor stands in the middle of the room with two long sticks held vertically with one end standing on the floor (against the corner with the wall). One stick has a heavy weight attached to the top.

Instructor: *When I let these go, which one will hit the ground first?*

Hands shoot up and a few muttered responses are heard. Some hands are hesitantly retracted as students think twice about their initial intuitive response. Someone calls out, "They will hit at the same time."

Instructor: *Will they? How do you know this?* [Pause] *Everyone write down what you think and we will vote.*

Several minutes later the second instructor has drawn a rough voting table on the board, and the vote is quickly taken:

Same time	Weighted stick first	Unweighted stick first
20	7	4

The instructor asks for opinions: *Justine, why did you vote for 'same time'?*

Justine: *I'm not sure – I think because I know that everything falls at the same speed, same rate. The mass does not matter.*

Instructor*: That sounds reasonable. Someone who voted for weighted stick first- Mark - can you say why?*

Mark: *That seemed to make more sense to me before, but I'm not sure now. I think I'm going to change my mind.*

Instructor*: What about someone who voted for the unweighted stick? Yes Martin?*

Martin: *Because I think you have to take the rotation into account as well as the falling. The unweighted one has less rotational inertia so it will rotate faster.*

Instructor: *OK, you've heard three opinions. Talk about it with your neighbours and write down if you have changed your mind and why. We'll vote again in a minute.*

The results of the second vote are taken:

Same time	Weighted stick first	Unweighted stick first
21	3	6

Some students have changed their minds to alternative and more plausible (to them) explanations.

Instructor: *OK, let's do it.*

There is silence and full attention as the two sticks fall, and two distinct sounds are heard.

Instructor: *Which one was it, Robyn?*

Robyn: *The lighter one.*

The demonstration is repeated several times with the unweighted stick clearly hitting the ground ahead of the weighted stick.

Instructor: *It seems that Martin may have had a good explanation. Martin, would you like explain your ideas again?*

… … and so the new line of reasoning is pursued as students must rethink and reformulate their beliefs and understandings, and write down a few notes to themselves.

The process described here is not accidental; the instructors know the likely outcomes of students' thinking and how they will vote despite the preceding problem-solving activity, which focussed on rotational motion. Previous research in physics learning (Duit, 1995; Duit et al., 1992; Halloun & Hestenes, 1984; McDermott, 1984) has consistently indicated that students' ability to use algorithms to answer physics questions is not necessarily related to their understanding of the underlying physics concepts. It has taken about 15 minutes to give students a chance to share and reconstruct their knowledge. Even so, the teachers know that not all students will consistently apply such reasoning in the future.

The above is not an actual transcribed lesson. It is simply typical of the activities and strategies adopted in the Studio and how students respond. It illustrates the time-consuming nature of such instructional approaches compared with more didactic lecturing or telling strategies. Students do not leave the Studio with a comprehensive set of lecture notes in their hands. If they have been sufficiently organised and self-motivated they will have read the chapter and written their own notes prior to coming to class but only about half of the students actually do this.

1.14 Review of Chapter 1

In this chapter I have outlined the genesis of the Studio approach for teaching physics at the undergraduate level and how Curtin University of Technology was prompted to implement a Studio course. This study has been set up to examine the educational effectiveness of the first year physics Studio course. A larger group of engineering students also study the same units but in a traditional lecture/tutorial course, providing a control with which to compare the Studio course. The structure and organisation of both courses have been outlined.

In the next chapter, I review literature related to the five main areas that underpin this study: cognition, learning physics, learning environments, epistemological beliefs and the nature of human beliefs.

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CHAPTER 2: REVIEW OF LITERATURE

2.1 Introduction

In this chapter, I will review the literature that is relevant to various aspects of this study. This includes literature related to cognition, epistemological beliefs and belief change, student learning in higher education, teaching learning in physics, in particular, innovative teaching methods, and research on learning environments. I begin with cognition in part because this is an education study and in part because cognition applies to the development of knowledge through research.

2.2 Cognition

2.2.1 Historical development of cognition theories

Cognition covers all modes or ways of *knowing* – perceiving, remembering, conceiving, judging and reasoning (Drever, 1964, cited in Richardson, 1987).

I begin my journey into cognition after the period of behaviourism. To adopt a behaviourist philosophy is to think of learning in terms of only the environment and behaviour of a person – leaving their mind as an impotent observer. Cognitive science is built on behaviourism in that it too neglects consciousness but favours a form of unconscious machinery behind thought and behaviour. Cognitive scientists believe that symbolic processes mediate between stimulus and response, and ignore biological change as part of the learning process. The mind is conceptualised as the body's 'software', controlling its behaviour as a computer program controls the behaviour of a computer (Leahey & Harris, 1997).

Evolutionary psychology (sociobiology) is concerned with the biological evolution of mind and behaviour. Developmental psychology not only acknowledges learning and maturation in the developing individual, it also assumes that the person is an *active* participant in the learning process, spontaneously moving from childish learning and cognition to the sophisticated adult modes. It is at this point, and from this position, that I begin to consider learning and cognition.

The differentiation or demarcation between philosophy and psychology impacts in a number of ways on this study. Psychology was originally part of philosophy and inherited many of its questions and processes. The problems relating to how we know and how minds operate have since become part of psychology. Epistemology, which deals with questions about the nature of human knowledge, is still considered a sub-discipline of philosophy. However, epistemological beliefs, or what humans know or believe about knowledge and knowing, have been investigated by psychologists rather than philosophers.

In tracing the development of recent theories of learning, I will go back only as far as the early-middle part of the last century, to relative contemporaries, Jean Piaget and Lev Vygotsky. It is possible to delve further into history to trace the origins of their work, but this does not add usefully to my study.

Piaget

Jean Piaget was a psychological theorist in the European developmentalist or Leibnizian tradition. Leibniz described the mind as an active entity, developing itself through inner-directed principles toward ever greater perfection. This was in contrast to the English empiricist tradition that depicted the mind as passive, building up knowledge by receiving and copying sense impressions (Leahey & Harris, 1997).

Specifically, Piaget was a genetic epistemologist, primarily interested in the development or evolution of knowledge in learners. In order to study such development, he elected to focus on children as they grew to know about the world around them. Piaget was also a biologist. His theoretical knowledge in this sphere, perhaps, enticed him to draw on such processes as homeostasis and Darwinian evolutionary theory to explain cognition and cognitive change in individuals.

Piaget believed that the human being was a developing organism, not only in a physical and biological sense but also in a cognitive sense. The tendency of all organisms towards self-preservation was hypothesised to extend to knowledge development; knowledge changed in response to environmental (physical or social) pressures. Piaget {cited in Fosnot (1996a)} described *equilibration* as “a dynamic process of self-regulated behaviour balancing two intrinsic polar behaviours – assimilation and accommodation”. Assimilation, matching experience to existing knowledge, preserves the essential structure of pre-existing knowledge. Accommodation is conceptualised as a change in knowledge structures in response to irreconcilable problems (contradictions) with the experienced world. Intellectual adaptation is a process of achieving a state of balance between assimilation of experience into the deductive structures and the accommodation of those structures to match the experience.

Piaget suggested three responses to contradiction:

- Ignore and persevere with initial scheme/idea intact.
- Hold both theories simultaneously – each holds for specific cases.
- Construct a new notion that resolves the prior contradiction.

These ideas have re-surfaced many times since as ways that students deal with difficult or contradictory ideas or observations in physics. Piaget used many physics or scientific examples in eliciting children’s knowledge states and the development of logical reasoning (Piaget, 1972).

Perhaps Piaget’s greatest, yet least acknowledged, contribution to the study of cognition was his naturalistic, interviewing method of inquiry, which pre-empted many later studies on children’s scientific understandings.

Vygotsky

Vygotsky, also a psychologist, was interested in the development of language as it applied to learning. Language is a key social process and hence Vygotsky emphasised the importance of social interaction in the development of knowledge. He also saw metacognitive awareness as a key element in learning (Rieber & Carton, 1987).

Vygotsky differentiated between spontaneous and scientific concepts. Spontaneous concepts emerge from the child’s own reflection on experience. Scientific concepts do not imply *scientific* as we might interpret it; scientific knowledge is anything learned through *teaching* or formalised learning rather than through everyday interactions with individuals, society or the environment (Finn, 1997; Rieber & Carton, 1987).

Many curriculum innovations have arisen out of Piagetian philosophy even though Piaget was not an educator and wrote little about the teaching process. More recently, the Vygotskian notion of the ‘zone of proximal development’ has influenced research on teaching. Although both Piaget and Vygotsky made it clear that their psychological work was educationally important, neither carried through to any extent with the educational application of their ideas (Beveridge, 1997; Driver, 1982).

Critiques of Piaget and Vygotsky

The works of Piaget and Vygotsky are not without criticism. Piaget’s developmental stage theory has not held up to critical research, his ideas are often considered too abstract, he has employed faulty logic, and his theory has no implications for instruction (Modgul & Modgul, 1982). Vygotsky’s work was socio-historically based, a product of the ideological milieu of Russia in the 1920s and 1930s, which has little relevance today (Finn, 1997).

However, von Glasersfeld (1995; 1996), who leans heavily on Piaget as the basis for his work, has also been influential in guiding and providing a theoretical basis for research on teaching and learning.

2.2.2 Constructivism

Constructivism is a set of beliefs about knowing and knowledge – what it is and where it comes from (von Glasersfeld, 1993). Hence, it is a theory of knowing rather than a theory of knowledge. If learning is conceptualised as *coming to know*, it can, and perhaps should be, examined within a constructivist framework. While constructivism is not, nor does it define, a particular set of teaching behaviours, it has been used to guide teaching approaches and teaching methods. See for example Fosnot (1996b), Steffe and Gale (1995) and Tobin (1993). Moreover, it serves as a useful referent to analyse the learning potential of any situation (Tobin & Tippins, 1993), particularly science, mathematics and tertiary education situations Hendry (1996).

Constructivism in research and education

There are many forms of constructivism (Ernest, 1995; Good, Wandersee & St Julien, 1993) and many ways of being constructivist (Bettencourt, 1993). Ernest (1995) provides a useful way of viewing the links between various constructivist positions and teaching. See Table 2.1. He identifies a spectrum of seven different research paradigms, each of which has an ontology, epistemology and methodology. Ernest has added to these a fitting pedagogy. In effect, he has combined "alternative epistemologies in education" with "alternative paradigms research". He bases his categories on the positions outlined by various contributors to the book in which his chapter appears. The seven paradigms are: Traditional empiricism, Information-processing theory, Trivial constructivism, Sociocultural cognition, Radical constructivism, Social constructivism and Social constructionism.

Ontology – the nature of reality and truth

Ontology is a theory of existence concerning the status of the world – both physical and biological. The traditional empiricist view, on which physics is arguably based, views the world as objectively real. A constructivist position is that the world may be real but we have only our experience as a way of knowing it. von Glasersfeld thinks of *radical* constructivism as *post-epistemological* – meaning that it is not concerned with the question of knowledge as a representation of truth, but it focuses on the manner in which knowers construct 'viable' knowledge. The concept of *viability* replaces the concept of *truth*.

Epistemology

An epistemology is a theory of the nature, origin and justification of subjective (individual) knowledge and conventional (shared) knowledge. Epistemology as a word has two main contexts of use – psychological and philosophical. Psychology is concerned with the nature, structure and development of knowledge, especially individual knowledge. In psychology, epistemology refers to theories of knowledge growth and development, structures of knowledge and general theories of conditions of learning. On the other hand, in philosophy, epistemology is a synonym for

Table 2.1. A summary of various constructivist research paradigms with fitting ontologies, epistemologies and pedagogical practices, showing the continuum from Traditional empiricism (non-constructivist) through to Social constructionism. Modified from Ernest (1995).

Paradigm	**Ontology**	**Epistemology**	**Pedagogy**
Traditional empiricism (Neo-positivist)	Naïve realism of science - the world is objectively real and experienced.	Objectivist – true and certain knowledge is possible/exists. Minds are mirrors of nature. Knowledge is the correspondence with or picture of truth	Transmissive. Passive-receptive view of learning. Errors or misconceptions due to faulty learning or carelessness
Information-processing theory (Neo-positivist)	Naïve realism of science - the world is objectively real and experienced.	Objectivist – true and certain knowledge possible/exists. Mind as computer. Recognises that knowing involves active mental processing of pre-existing knowledge.	Strategies in line with the acquisition, storage and retrieval of pre-existing and processed knowledge. Accounts for 'alternative conceptions'.
Trivial constructivism (Borderline – but not constructivist)	Naïve realism of science - the world is objectively real and experienced.	Objective knowledge. The active mind constructs knowledge. Adheres to von Glasersfeld's first principle - *knowledge is not passively received but actively built up by the cognising subject*.	Strategies involving reading and writing - as forms of knowledge representation.
Sociocultural cognition	Naïve realism of science - the world is objectively real and experienced by human society.	Fallibilist. Adheres to von Glasersfeld's first principle - *knowledge is not passively received but actively built up by the cognising subject*. Learning has a cultural dimension - existence and knowledge of symbolic cultural artefacts.	Importance of social context. Goal orientation. Apprenticeship or 'legitimate peripheral participation'. Cumulative mastery over skills. (Fits well with 'formal education').

Table 2.1 continued

Paradigm	Ontology	Epistemology	Pedagogy
Radical constructivism	World is real but not knowable. Makes no pre-suppositions about the world behind the subjective realm of experience.	Fallibilist, sceptical, anti-objectivist and non-absolute. Mind as adaptive – fitting the organism to survive within an experiential world. Knowledge as a whole is problematic - doubtful and questionable. ‘Post-epistemological’. All knowledge, including scientific conceptions, is human construction.	Multi-faceted, sensitive to individual construction. Teacher as facilitator of learning. Socially-agreed knowledge. Recognises meta-knowledge, unique personal conceptions and the role of knowledge-sharing and negotiated meaning.
Social constructivism	Sophisticated and realist. A real world but we have no certain knowledge of it.	Fallibilist. Conventional (shared) knowledge is that which is lived and socially accepted. Knowledge as a whole is doubtful and questionable.	Eclectic. Relies on the medium of language. Social negotiation of meaning.
Social constructionism	World is ‘social reality’ – a universe of persons residing in the world.	Fallibilist. Conventional (shared) knowledge is that which is lived and socially accepted. Knowledge as a whole is doubtful and questionable. Prioritises the social above the individual.	No real pedagogy. This paradigm is more used in psychology than education.

Fallibilist means ‘error-prone’.

the theory of knowledge, its justifiable basis and logical categories of knowledge.

Methodology

A methodology is a theory of which methods and techniques are valid to use to generate and justify knowledge in accordance with the epistemology.

Pedagogy

Pedagogy is a theory of teaching or the means to facilitate learning, in line with the ontology and epistemology.

I make no attempt in Table 2.1 to provide a cohesive summary but rather a framework to enable me to position the pedagogical perspectives of the Studio as well as a provide a rationale for my own research methodology, which is discussed in Chapter 3. Ernest notes that the distinction between social constructivism and radical constructivism is becoming less clear-cut as the social dimension is more fully encompassed by radical constructivism. Other than traditional empiricism, all paradigms support the following pedagogical assumptions or values:

1. Learners' previous constructions mediate learning.
2. Diagnostic teaching.
3. Metacognition – strategic self-regulation.
4. Multiple representations of complex ideas.
5. Importance of learners' goals and their relation to teachers' goals.
6. Awareness of social contexts and everyday knowledge.

However, the following are some of the stronger implications that follow from *radical* and *social* constructivism:

1. Knowledge, taken as a whole, is tentative and uncertain.
2. The focus of concern is not just the learner's cognitions, but their beliefs and conceptions of knowledge as well (what I later refer to as their epistemological beliefs).
3. The teacher's beliefs, conceptions and personal theories about subject matter, teaching and learning impinge on the teaching process.
4. Pedagogical emphasis on discussion, collaboration, negotiation and shared meaning are implicit in the social construction of knowledge.

Table 2.2 is a summary of what researchers with different epistemological positions offer about the educational process.

Table 2.2. Conceptions of teacher behaviours that reflect various epistemological positions.

Epistemological position	**Researcher**	**Teacher behaviour consonant with the given epistemological position.**
Traditional empiricism		Teachers talk *at* rather than *with* their students. Students' learned disposition is therefore to expect such instruction. Top-down processing of information i.e. a problem should be solved by applying 'common sense'.
Radical constructivism	E. von Glasersfeld	Teachers are concerned with what is in the minds of students. They recognise that 'misconceptions' to a physicist may be 'viable conceptions' (i.e. truths) to a students. They use countering examples that are within the experience of students. They emphasise that particular conceptions may have been considered scientifically viable in a given historical or practical context rather privileged truths.
Social constructionism	K. Gergen	Teachers recognise that learning is achieved through social processes and is represented in words and other forms of communication. Meaning is achieved through the coordinated efforts of two or more persons. Hence, teachers are facilitators, coordinators, advisers and tutors, and limited educational gain can be derived from the traditional lecture format.

Within von Glasersfeld's theory of radical constructivism, teaching cannot be by telling, but rather '"orienting" the conceptual construction of students (von Glasersfeld, 1992). In order to teach, therefore, one must construct *models* of students so that the required 'knowledge' can be presented in ways that are accessible to students. This means being aware of, and respecting, their pre-existing knowledge. He further suggests that while teaching is a social activity (in that it involves others that the teacher intends to influence), learning is a private activity in the sense that it has to take place in the student's own mind.

Von Glaserfeld (1993) gives the following implications for a theory of instruction:

- Teachers must assess prior knowledge of students.
- Students must demonstrate that their answers make sense to them.
- Teachers must try to understand students' thinking.
- Students must explain their own reasoning processes.
- Fun fosters motivation.
- Successful thinking is more important than 'correct' answers.
- Constructivist teachers cannot justify that what they teach is 'true' – but the best/most logical at the time. In science in particular, a teacher should never present a solution as the only solution.
- Assessment must be in relation to what one wants to teach. It is important to assess how the students think or respond to problems, rather than merely the end result.

Hendry (1996) offers a pragmatic, rational compilation of various expressions of constructivism in the form of a set of key principles and their application to classroom teaching. He bases these on two broad hypotheses which he attributes to Lerman (1989): (1) knowledge is actively constructed by an individual, and (2) coming to know is an adaptive process which organises an individual's 'experiential world'. The principles are:

1. Knowledge exists in the minds of people only, i.e. in the minds of the students and teacher, not in books, words, on computer screens or in

talk. This principle does not deny an external reality but asserts that knowledge does not exist as external entity independent of the knower. Social constructivism is seen by Hendry to be at variance with this because it holds that knowledge is shared and hence, can exist as an objective entity in social interaction.

2. The meanings or interpretations people give to things depend on their knowledge. Teachers and students each generate their own meanings for the curriculum, instructional materials and practices, and language and behaviours of the teacher.
3. Knowledge is constructed from within, in interrelation with the world. Teachers or teaching methods per se do not change students' ideas; change occurs through students' interrelation with the world, of which teachers are a part. Hence, learners should be encouraged to express their ideas or knowledge as part of the learning or sense-making process. Students are ultimately responsible for their own learning.
4. Knowledge can never be certain. Knowledge is 'valid' if it remains unchanged – i.e. the knower perceives no contradiction to their knowledge. We cannot determine that we know the world as it is because we cannot 'step outside' our knowledge constructed from within, to compare it with the world. Scientific knowledge can never be presented as exact. Because each student has different knowledge, the language that teachers use cannot be assumed to convey specific meanings. Teachers must have acceptable subject knowledge and be able to ascertain or infer reasonable knowledge about what students are thinking and how this thinking may develop.
5. Common knowledge derives from a common brain and body, which are part of the same universe. The commonality in our biological make-up determines, to some extent, common processes and interaction. Students and teachers share particular knowledge. They can share the same perceptual knowledge of an event or entity (a computer program for example).
6. Students' alternative conceptions arise from common experiences and hence are 'common sense'. From the child's point of view, they are sensible and useful, and are taken by the child to be common

knowledge – to the extent that they are ‘obvious’ and not in need of justification.

7. Knowledge is constructed through perception and action. Generally, logico-mathematical and ideational knowledge organise perception and action, which in turn organise the world. People construct new forms of knowing through perception and action (which includes communication) particularly if their existing knowledge becomes unsustainable or ceases to remain viable. Classrooms must therefore contain a variety of manipulative materials, and students encouraged to make their ideas explicit.
8. The goal of learning may be undermined (for students as well as teachers) if there is undue emphasis on reward for students to get ‘correct’ answers instead of a focus on the process of developing knowledge.
9. Construction of knowledge requires energy and time. It is suggested that the effort of construction depends partly on affect. People sense or ‘feel’ the threat of cognitive disturbance and may either apply mental effort to achieve new knowledge (which results in pleasure) or they may selectively ignore or withdraw from interaction with that part of the world. Therefore, teachers must attempt to cultivate a ‘non-threatening learning environment’ for learners. Discussion, collaborative work and sharing of knowledge and beliefs promote knowledge construction.

Scott, Asoko and Driver (1991) provide a review of science teaching strategies that are broadly based on a view of learning as conceptual change. Cognitive conflict strategies include *discrepant events* and *conflict between ideas.* A second group of strategies focus on developing ideas consistent with a scientific viewpoint. Instead of recognising alternative frameworks as errors, teachers accept that students’ ideas contain some useful explanatory elements. One strategy is to develop bridging analogies using students ‘correct’ ideas as anchoring conceptions.

Social constructivist learning environments

Many researchers have drawn on Vygotsky's work to support hither-to unacknowledged socio-cultural aspects of learning science.

> *... scientific knowledge is both symbolic in nature and also socially negotiated. The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature.*
>
> (Driver, Asoko, Leach, Mortimer & Scott, 1989)

These people adopt the view that scientific knowledge is not an objective 'given,' but is the consensual knowledge of and within the scientific community. Learning science is therefore seen to involve more than the individual making sense of his or her personal experiences but also being initiated into 'ways of seeing' which have been established and found to be fruitful by the scientific community. Such meaning-making is mirrored by children discussing scientific concepts. Solomon (1993) proposes that the process by which students construct notions for explaining the meaning of events in their daily lives is more social than personal. However, assertions made by students are not weighed and tested by logic but only paraded, as it were, for social recognition.

> *In the end, familiarity wins the day. What is recognised [by the group] is consensual: what is consensual is recognised; disagreements are either resolved or simply ignored.*
>
> (Solomon, 1993, p. 88)

Those who advocate a stronger social dimension to the concept of constructivism focus on both language and emotional interaction to promote learning. These people generally view *social* as *consensual*, meaning socially agreed, rather than social in a communication sense. When von Glasersfeld (1992) talks of social, he refers to 'others,' being those with whom the subject communicates. He is clear that one cannot know the mind of others, nor the social context in which one grows up, any more than one can know the physical world.

Limitations of constructivism

> *Constructivism is an unpopular view. The notion that, as far as knowing goes, we are unconditionally trapped in our own ways of seeing and conceptualising, irks a lot of people.*
>
> Von Glasersfeld (1992, p.32)

How does constructivism fit with physics? According to von Glasersfeld (1993), not well, since the aim of physics is to understand the real world. He suggests that most physics teachers have little sympathy for constructivism; that they prefer to talk as though they were disassembling an absolute reality. Physics teachers' concerns that students don't like uncertainty and want to know how things really are influences the way they teach physics. Nevertheless, von Glasersfeld is acknowledged by the physics education research community and his ideas are beginning to underpin some teaching and research initiatives.

Ernest (1995), and others in this book, warns against a romanticism of constructivism in teaching. By this they mean overly sentimental views of the student or sanctioning of anything as expressions of the student's individual creativity.

Tobin and Tippins (1993) argue that teaching approaches or methods based on a set of simple constructivist principles has the effect of trivialising constructivist beliefs or constructivism's potential as a referent. As a referent, constructivism can be used to analyse the learning potential of *any* situation. It provides an alternative perspective for improving lecturing or any other form of instruction, without the need to restructure the education process along constructivist principles.

2.3 Learning physics

> *Research shows that students learn … science concepts and principles only to a limited degree, that sometimes students persist almost totally with their pre-instructional conceptions and that sometimes students try to hold on to two inconsistent approaches – one intuitive and one formal*
>
> (Treagust, Duit & Fraser, 1996, p. 2)

2.3.1 Physics knowledge

Knowledge within a discipline is often differentiated into declarative and procedural knowledge. Declarative knowledge is ‘knowing *that* …’ and refers to content and facts of a discipline. Procedural knowledge has to do with skills, ‘knowing *how* to …’ These skills can be physical or manipulative, or they can be internal (mental) such as knowing how to apply mathematical rules to solve problems. Procedural knowledge can be general, such as deductive reasoning, or specific as in operating a particular piece of apparatus or using a computer program. A third type of knowledge that is of interest is self-knowledge (Dillon, 1986). This is knowledge about one’s own knowledge, strengths and limitations. Self-knowledge, or metacognition, may pertain to the state of our own declarative or procedural knowledge.

Another type of knowledge not encompassed above is conceptual knowledge, which has more of the characteristics of beliefs than knowledge. Because conceptual knowledge in physics (or science) has considerable effect on students’ higher learning in the subject, it will be treated as another form of knowledge.

Much literature focuses on the nature of students’ scientific conceptions (Driver, 1989; Novak, 1988; Pfundt & Duit, 1997), research on the cognitive processes involved in conceptual change (Hewson & Hewson, 1991; Posner, Strike, Hewson & Gertzog, 1982) and teaching methods aimed at inducing conceptual change (Grayson, 1996; Hewson, 1996; Schecker & Niedderer, 1996; Scott et al., 1991). I will confine the remainder of this discussion primarily to studies that are related to physics conceptions or which appear most useful in understanding the development of students’ physics thinking.

In the 1970s, research in science education began to focus on the conceptual models that lie behind students’ reasoning in particular science domains. Various interpretive and interview techniques using individuals as the unit of study began to supplant or add to the more traditional quantitative and group study methods. Hence, students’ individual knowledge structures and semantic frameworks became the focus of research – following the general and by now, more popular view that learning comes about through the learner’s active involvement in knowledge construction.

2.3.2 *Nature and status of conceptions*

A review of the literature (McCloskey, 1983; McDermott, 1984; Pfundt & Duit, 1997; Wandersee, Mintzes & Novak, 1994) suggests there is wide consensus about the characteristics of naïve or alternative physics conceptions, and students who hold them. For example:

1. Alternative conceptions appear to be grounded in physical experiences and social interaction during a child's developing years (Carey, 1985; Lewis & Linn, 1994). Alternative conceptions serve as naïve explanatory constructs that enable a person to understand, explain or predict events in their world.
2. Students apply these conceptions indiscriminately and inconsistently in different contexts.
3. Conceptions are resistant to change, despite teaching aimed at achieving change. In the case of physics students, many alternative conceptions remain intact through their tertiary education.
4. A limited number of core concepts is sufficient to explain a wide variety of student actions in different situations.
5. Students use different concepts or facets of them in situations that physicists classify as structurally equivalent (Chi, Feltovich & Glaser, 1981).
6. Students' conceptions appear to undergo progressive evolution, or piecemeal change, during the school years, as more detail is added to their knowledge of phenomena (Champagne, Gunstone & Klopfer, 1985; Erickson, 1980; Stavy & Berkovitz, 1980; Vosniadou, 1994).
7. Different research methods aimed at probing alternative conceptions often result in claims of differences in the nature and status of students' conceptions (Driver, 1989).

Mental models

Some physicist-educators focus more on students' mental pictures or explanations – called mental models – and less on the nature of cognitive structures thought to be responsible for them.

Mental models are peoples' views of the world and themselves, formed through interaction with the environment, with others and with the artefacts of technology (Norman, 1983). The models provide explanatory power for understanding the interaction. However, peoples' mental models are incomplete, unstable, without firm boundaries, unscientific (or even superstitious), parsimonious and used inconsistently. Norman asserts that people maintain behaviour patterns they know are superstitious because they cost little physical effort and save mental effort. He suggests that saving mental effort is an important motivating mechanism.

Mental models research has revealed much about physics students' thinking. Although *models* suggest a type of structure consisting of a number of parts, the question of the 'grain size' of conceptual knowledge has led others to postulate smaller, more basic units of knowledge that are responsible for students' responses in a variety of situations or contexts. These basic units may or may not be, context-specific. The traditional idea of parsimony of (scientific) knowledge has an appeal for physicist-educators. The belief that all knowledge has a structure dependent on a small number of basic, well-defined elements has prompted researchers to evaluate the effect of instructional methods by assessing more fundamental aspects of physics learning (Galili & Hazan, 2000).

p-prims

DiSessa (1983; 1993) proposes that intuitive knowledge may take the form of a very basic unit – a p-prim or phenomenological primitive. These are primitive notions, without specific context, and which stand without significant explanatory substructure or justification. They are relatively minimal abstractions of simple common phenomena that have priority status. The p-prim *rigidity* initially has a higher status for students than *springiness,* and will influence the way they interpret physical phenomena. To a physicist, springiness is a useful construct but rigidity is essentially irrelevant to any deep explanation of the way things happen. Other persistent false p-prims are *dying away*, *force as mover* and *force as spinner*.

Roschelle (1991) identified students' use of p-prims such as *pulling*, *balancing*, *resistance* and *attraction*, in both scientific and non-scientific ways. He explains that p-prims function as pre-made explanatory structures that can be adapted to make sense of complex new phenomena at a level more integrated than arbitrary reasoning based purely on observation. He suggests that they act as *generative metaphors,* which are essential to forming integrated explanations that generalise across qualitative cases. Roschelle, using the computer software, The Envisioning Machine (Roschelle, 1991) and Roth using software Interactive Physics (Roth, 1996) have both focussed on students' language as they moved toward science understandings and scientific language.

Facets

Minstrell (1989, p. 12) defines a facet of knowledge as a "convenient unit of thought, a piece of knowledge or strategy, used in addressing a particular situation". Facets may relate to content, may be strategic, or a generic bit of reasoning. Minstrell has documented many facets that students consistently use in physics teaching/learning situations. His position is that all student knowledge is valuable – it may just need some modification, limitation or elaboration. All facets can lead to better physics knowledge.

2.3.3 Conceptual change

Although there are many studies on conceptual change, a viable theory of the dynamics or process of conceptual change is not, as yet, agreed. It is not only difficult to effect change, it is also difficult to determine when and if any measured change is permanent.

Reflecting historical change in scientific theories

There is an attractive but not altogether tenable proposal that changes in students' conceptions from non-scientific to those in accord with scientists' views, reflect or follow the same changes that have occurred in historical changes to accepted scientific theories. Evidence and support for such an idea comes from a number of sources (Posner et al., 1982; Thagard, 1992; Wandersee et al., 1994). Non-Newtonian thinkers display ideas not unlike pre-Newtonian Aristotelian explanations of motion (McCloskey, 1983).

Posner et al (1982) propose a model for conceptual change, called the conceptual change model (CCM), which parallels scientific theory change. Students must first become dissatisfied with their own conception and find the need to develop a new conception that is understandable, plausible (in terms of their prior experience), and fruitful (in that it ‘explains’ more than the older conception was able to). They suggest that when this occurs, students will change to the new conception and drop their old one, as with a change from an old to a new scientific theory. Thagard (1992) notes the similarity but doubts that the driving force of greater explanatory coherence is present in student’s reasoning.

Nature of conceptual change

Conceptual change involves a re-structuring of a person’s conceptual or mental framework. This could occur as:

1. Conceptual extinction or total loss of the old conception. This is not thought to occur since students appear to retain at least part of their naïve ideas.
2. ‘Conceptual capture’ in which students make links between what they did not know and what they did (Hewson & Hewson, 1991). This is a type of knowledge consolidation.
3. Conceptual exchange – the change or reversal in the status of competing conceptions (see below).

Strength or resilience of initial conceptions

White and Gunstone (1989) prefer the term ‘belief change’ to conceptual change because of the apparent strength of students’ initial conceptions. This implies that students will revert to a belief if something they have learned or are required to learn contradicts that belief. Such beliefs have been shown to be so strong that a student’s memories of events can be distorted to fit their initial beliefs. A student’s beliefs about electric current made him/her remember observations of a demonstration that aligned with their initial conception rather than remember what actually happened.

In the discipline of psychology, a person’s beliefs are regarded as stronger than their knowledge. A belief needs no warranting or justification. It is a person’s unquestioned knowledge about the world as it appears to them. This sits well with White and Gunstone’s views.

Types of conceptual change

Some changes are easier to effect than others suggesting that conceptual change is a multidimensional phenomenon. Tyson, Venville, Harrison and Treagust (1997) compared the results of different conceptual change studies and found a similarity in the nature of conceptual change. They describe the change categories as *addition* in which a new conception is added to existing mental framework, *revision*, in which there is a change to the existing framework. The latter is divided into *weak* and *strong revision*. Weak revision is akin to Piaget's assimilation and strong revision to Piaget's accommodation.

Dykstra, Monarch and Boyle (1992) use the terms *assimilation*, *accommodation* and *disequilibration* which Piaget introduced in the context of learning. Assimilation is the recognition that an event fits an existing conception – a 'weak' knowledge change. This process is also a selective ignoring of discrepancies not deemed salient. Assimilations strengthen existing beliefs. Accommodation is a change in a belief (conception) that enables an event to be assimilated where it would not be under a previously held conception – a 'strong' knowledge change. Accommodation can only follow disequilibration, where a student's expectations are not met – where an event does not meet a student's expectations.

Conceptual change teaching strategies

Most classroom-based conceptual change strategies involve students being encouraged to acknowledge and then make some judgement about the relative merit of different, often contradictory, conceptions. One such strategy involves the use of *discrepant events* (Fensham & Kass, 1988; Osborne & Freyberg, 1985), where students are confronted with clearly contradictory experiences or observations, or where their conceptions are shown to clash with those of scientists. The aim is for students to exchange their ideas for those of scientists. Other approaches have been more direct teaching initiatives, such as *bridging analogies* (Stavy & Berkovitz, 1980) or *concept substitution* (Grayson, 1996) that build on appropriate conceptions that learners are known to have, and progress them toward more scientifically acceptable ideas. The correct ideas act as *anchoring conceptions* (Brown & Clement, 1989). A further strategy called *contrastive teaching* (Schecker & Niedderer, 1996) encourages students to actively compare intuitive and scientific ideas. Dykstra et al (1991) refer to the need for strategies that promote *progressive differentiation* of concepts such as heat and temperature or velocity and acceleration.

Problems arising from conceptual change teaching are the nature and endurance of the conceptual change. Students may allow the new conception to co-exist with incorrect ones for the duration of the topic, making little or no effort to reconcile discrepancies, and then revert to their initial ideas later or they may simply continue holding contradictory conceptions which they apply differently in different contexts (Scott et al., 1991). In each case, there is no change to the conception, simply the addition of a new idea to the conceptual framework.

Many have suggested that conceptual change is, indeed, an incremental process rather than as a result of a single exposure to, and apparent acceptance of, the new idea (Duschl & Gitomer, 1991; Roschelle, 1991). Hewson and Hewson (1991) have suggested that students do not 'unlearn' initial ideas but merely change their status as newer ideas become more plausible and useful. The previous conception is thus downgraded in status, but does not disappear from the knowledge framework. Roth (1996) suggests that students change in the meaning that they attached to particular words (or they way they use the words) as they slowly develop more scientifically acceptable knowledge and reasoning.

2.3.4 Metalearning and metacognition

Metalearning is the conscious control over one's learning. Pintrich, Marx and Boyle (1993) suggest that there is no rationality in students' approach to conceptual change, which is probably driven by a range of irrational, social and motivational forces. Hence, many students need to be taught such a skill, and over a period of time. Novak (1982) writes in support of Ausubel's (1963) Meaningful Learning theory in which students are encouraged to make sense of what they are learning, to constantly relate new knowledge to what they already know. Meaningful learning is the opposite of rote learning. This approach also encourages the learner to be aware of his or her own knowledge and beliefs. White and Gunstone (1989) also suggest that for effective (conceptual change) learning to take place, students need to be encouraged, through a structured learning environment, to be taught how to reflect on their understanding and take greater responsibility for their learning. Students must make a conscious effort to learn.

Metacognition is a mental activity that is a combination of student knowledge, awareness and control relevant to their learning (Gunstone, 1992).

> *Students … have conceptions about teaching and learning (knowledge), have perceptions of the purpose of and their progress through any teaching/learning activity (awareness), and make decisions and act in particular ways during the activity (control)* (p. 135).

White (1998) talks about four facets to metacognition – knowledge of processes of thinking, awareness of one's own processes, the ability to control them, and willingness to exercise that control. The first two are prerequisites for the second two, but it is arguably the second two that underpin successful metacognitive activity. White believes that teaching students metacognitive skills such that they willingly implement them in learning may take a concerted effort over months or years if habitual 'not-thinking' has been the dominant student behaviour.

With regard to personal motivation, White and Gunstone (1989) suggest that students will accept training in metacognition when they are dissatisfied with their present style of learning and find metacognition plausible, intelligible and fruitful. It is difficult however to achieve the dissatisfaction where students are resistant to change and difficult to demonstrate fruitfulness, at least in the short term.

2.3.5 Other factors influencing physics learning

Other factors thought to influence students' physics learning are motivation and goals, 'frames of thinking', ideas about learning physics and ideas about the nature of physics. These are often representative of individuals' different traits (Jonassen & Grabowski, 1993) or different dispositions.

Niedderer and Schecker (1992) refer to general elements of cognitive systems, for example 'frames of thinking', which seem to be important for physics learning. One of these comprises difference between everyday thinking and scientific concepts and theories, in particular, students' views of "the task of physics."

> *Students tend to see the task of physics in investigating single problems of the everyday-life world with sophisticated methods. They tend to work on theoretical and abstract problems by transforming them into one special situation of the real world. They are not oriented towards looking for abstract and general concepts and principles*.
>
> Schecker (1985), cited in Niedderer (1992, p. 152)

Chapman (1993) contrasts *formal* with *everyday* reasoning and indicates that the factors, which drive thought processes in our everyday lives imply different goals and outcomes from those used in scientific thinking. Formal reasoning is characterised by explicit premises, self-contained problems, established inferential methods, unambiguous solutions, limited 'academic' interest, and problems which are solved for their own sake and not for further ends. Everyday reasoning is characterised by no, or few, supplied premises, unconstrained problems, multiple possible solutions, few (if any) established procedures for solving problems, a solution which may not be confirmed as best, personally relevant problems and problems usually solved for a reason. It is clear, therefore, that students' intuitive and everyday ways of thinking will constrain their thinking about scientific concepts.

Another line of research asserts that there are fundamental qualitative differences in the ways students approach learning in realistic education contexts (Entwistle, 1987; Prosser & Trigwell, 1997; Säljö, 1987). Cognitive outcomes are dependent on the type of approach employed. A *surface level approach* is associated with gaining a 'passing grade' for a minimal amount of work. It results in low quality learning and a short-term focus on 'getting the right answer' rather than a problem-solving approach leading to a meaningful answer. A *deep learning approach* is the opposite. It is associated with meaningful learning and supported by an intrinsic interest in the task, a necessary condition for understanding. A third approach is an *achieving or strategic approach* in which learning activity is directed toward gaining as high a mark as possible.

There appears to be considerable discordance between what students think they are doing and learning in science classes and what their teachers think they are doing or learning (Duit, 1995; Gunstone, 1992). Gunstone provides the following list of high school students' apparent views of teaching and learning:

1. Students do not know the purpose of their activities – even when they have been explicitly told.
2. Students have extremely transmissive views of learning and teaching, believing that that teachers should 'teach' and students should 'learn'.
3. For students, the only short-term issue of importance in physics is often no more than getting the 'right' answer. Hence, processes, supporting arguments, alternative perspectives and links to other concepts are not considered important.
4. Students see lessons or units of work as discrete and not inter-related with other work.

Gunstone argues that such metacognitive conceptions are just as significant an influence on physics learning, as are various alternative conceptions about physics concepts.

The learning of physics at a tertiary level appears to suffer from similar problems. Prosser, Walker and Millar (1996) found that three quarters of students entering first year university physics courses studied using surface level approaches, learning to pass the tests rather than learn for understanding. Although many students said that physics was about the "study of the physical world", few approached their studies this way, or recommended that others did either.

Larochelle and Désautels (1992) give many examples of students from a first year university philosophy course that were invited and encouraged to reflect on and question ideas that were presented to them. Their sense of empowerment, and realisation that scientific knowledge was not ordained and that they could question the validity of different theories, gave them a perspective on science that had been absent from their high school experiences.

These beliefs or attitudes are not unique to undergraduate students. Tobias (1990) describes in detail the experiences of high-achieving 'second tier' (non-science post-graduate) students trying to make sense of traditional first-year introductory, calculus-based physics and chemistry tuition. These 'students' compared teaching and learning in physics with that in the humanities. Of their instructors, they reported: patronising styles', a tendency to embed concepts within problem-solving instead of using words, setting excessively difficult homework but too-easy, predictable and quantitative exam. There was an overemphasis on 'lecturing' – even when a teacher admitted that 'telling is not teaching' – delivered at a relentless pace with too little time for reflection about relationships or links to other areas and introduced too many formulas. Of classmates, they reported: bored and unexcited students, the majority only wanting problems and (particularly) solutions, not discussions about why or about conceptions. There was unwillingness to ask questions, no sense of class community, overemphasis on getting desired grades at the expense of the rewards of learning, focus on taking notes rather than discussing or thinking and a competitive rather than collaborative culture.

> *People act differently in physics. The seating arrangement militates against being social, integrated… …Physics is not a place where people befriend one another.*
>
> [Tobias, 1990 #346p. 65]

Seymour (1995) in describing reasons why physics undergraduates change courses provides many similar examples. Which came first, the teaching of physics or the expectation about how it should be taught? Those who 'succeed' in physics appear to be either a particular type of student who works best in the type of instructional environment customarily present in physics classes, or students who are able to adapt to the environment. There appears to be an expectation on the part of instructors (at least as perceived by students) that physics is to be presented and learned in a particular way. There appears also, to be a perception on the part of students that doing physics in a particular way (as modelled by teachers) results in success and so this must be the way to do physics.

2.3.6 Physics Education Research practices

The focus of much recent research within physics departments in the USA has been on evaluating the effectiveness of a variety of *interactive (or active) engagement* (IE) *methods* (Hake, 1998; Laws, 1997; Redish, Saul & Steinberg, 1997; Sokoloff & Thornton, 1997). *Interactive engagement* draws on the constructivist principle that learners must be mentally (and maybe also physically) active and purposeful for learning to occur. A transmissive pedagogy is deemed ineffective in engaging the majority in the class. Many interactive engagement methods have worksheets or other instructional materials that have been well researched in terms of their effectiveness in changing students' inadequate physics conceptions. One approach to the linking of research to the development of instructional materials is the cyclic process practised by the Physics Education Research Group at the University of Washington. In this process, research on student understanding explains or accounts for, the difficulties with current instruction. The results of the research are then used to design new curricula and teaching approaches, which lead to modified instruction. This process cycles in a helix of continuous educational improvement (McDermott & Schaffer, 1992).

A brief inventory of various instructional models is given in Table 2.3 and each is described below. Most of these instructional models use information technology in some way – either for displaying content or problems, collecting and projecting whole class responses onto a screen, for promoting interaction and discussion, for interfacing with laboratory equipment and graphical interpretation, or for communication between students or students and instructors.

In *Full Studio* classes, students are actively involved in exploring the physics using some laboratory equipment for most of the class time. The instructor may give short lectures. These classes tend to be more expensive than traditional lectures in terms of instructor time, space, and equipment required.

Physics by Inquiry was developed for pre-service teachers. Course materials guide students through a discovery program using simple equipment. There are no lectures, only two laboratory periods of two hours each.

Both the *Workshop Physics* class and the *Physics Studio* make strong use of computer equipment in an inquiry-style classroom. Many activities use instruments, such as motion detectors, interfaced to the computer. The computer stations also contain calculation and modelling tools such as a spreadsheet, programming language, and symbolic manipulator. These classes are held in two-hour periods in which most of the student time is spent with apparatus making observations and building mathematical models of their results. The classroom contains a central area for common demonstrations and many class periods may include brief lecture segments or whole-class discussions. These classes use worksheets (in Workshop Physics) or on-screen lessons (in the Physics Studio).

Table 2.3. Various interactive engagement physics teaching models. Developed from Redish (1996).

Full Studio/Workshop Models
1. Physics by Inquiry (L.McDermott, University of Washington)
2. Workshop Physics (P. Laws, Dickinson College)
3. The Physics Studio (J. Wilson, Rensselaer Polytechnic Institute)
4. Constructing Physics Understanding (F. Goldberg, San Diego State University)
5. Modelling Instruction in Physics (D. Hestenes & J. Jackson, Arizona State University)
6. Powerful Ideas in Physics (J. Layman, University of Maryland)
Discovery Labs
7. Tools for Scientific Thinking (R. Thornton, Tufts University; D. Sokoloff, University of Oregon)
8. RealTime Physics (R. Thornton, Tufts University; D. Sokoloff, University of Oregon and P. Laws, Dickinson College)
Lecture Based Models
9. Active Learning Physics System (A. van Heuvelen, Ohio State University)
10. Active Learning using a Classroom Communication System (J. Mestre, University of Massachusetts)
11. Peer Instruction with ConcepTests (E. Mazur, Harvard University)
12. Interactive Demonstrations (R. Thornton, Tufts University; D. Sokoloff, University of Oregon)
13. Desktop Experiments (B. Sherwood, Carnegie-Mellon University)
Tutorial (recitation) Based Models
14. Cooperative Group Problem Solving (K. & P. Heller, University of Minnesota)
15. Tutorials in Introductory Physics (L. McDermott, University of Washington)
16. Mathematical Tutorials (E. Redish, University of Maryland)

Laboratory-based models replace the traditional laboratory by a discovery type laboratory. *Tools for Scientific Thinking* is a series of guided discovery laboratories in mechanics and thermodynamics. The laboratories also use computer interfaced data-acquisition instruments. The focus is on a conceptual rather than quantitative approach.

RealTime Physics is a series of mechanics laboratories that can be used in a traditional structure. Heavy use is made of computer assisted data acquisition. A more quantitative version is used for calculus-based physics.

Peer Instruction ConcepTests: Several "concept tests" are used each lecture. The questions are concept oriented with distracters based on common student difficulties. Using an electronic system such as ClassTalk, students' answers are displayed on a projection screen. Students discuss the problem briefly with peers and then answer the question again. There is usually considerable improvement in students' understanding of concepts as well as their confidence about their understanding.

Active learning Physics System uses a series of worksheets in a large lecture format. Small segments of lecture are alternated with individual student activities and peer discussion. An electronic display system and peer discussion, similar to that described above, is also used.

Tutorial-based models replace a recitation (in which an instructor models problem solving) with a mini-lab in which the students carry out guided discovery experiments and learn reasoning in groups guided by worksheets.

Cooperative-Problem Solving involves students working together on realistic, context-rich problems. The problems, which may contain incomplete data, are intended to be too difficult for any individual student to solve. Students work collaboratively in pre-assigned roles.

Tutorials in Introductory Physics are group learning activities using carefully designed research-based worksheets which emphasise concept building, qualitative reasoning, and make use of cognitive conflict. Trained facilitators assist students resolve their own confusions. Another series of these in a *studio format* use data acquisition tools.

The Physics Education Group at the University of Sydney have also developed interactive, group-based tutorials for first year students.

2.3.7 Measurement of learning outcomes

The change from Aristotelian to Newtonian thinking is one yardstick by which the physics education research community can measure whether or not students are making productive conceptual change in physics knowledge (Thornton & Sokoloff, 1998). This particular change is regarded as important in physics because not only does it indicate that a student is able to apply appropriate reasoning in solving problems on linear and rotational mechanics, but it also influences students' reasoning in the application of principles of motion to sub-microscopic particles as required in the Kinetic Theory (Kesidou & Duit, 1993).

Two instruments widely used for this are the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992) and the Force and Motion Conceptual Evaluation (Thornton & Sokoloff, 1998). Hake's (1998) significant study of the effectiveness of different instructional methods used the FCI. He was primarily interested in comparing the relative effectiveness of traditional lecture-based instruction with various interactive engagement instructional methods. In order to compare groups of differing backgrounds and abilities and from different institutions (both secondary and tertiary), he devised a statistic known as the *average normalised gain*, <g> or <*gain*>. This uses pretest and posttest results and is the increase or gain in students results presented as a fraction (or percentage) of their maximum possible gain. There is further discussion of this statistic in Section 4.2.1.

The results of Hake's research showed, most notably, that lecture-based methods, either high school or university, did not result in an average normalised gain greater than 0.3. In contrast, all interactive engagement methods resulted in average normalised gains between 0.2 and 0.7. No method resulted in an average normalised gain greater than 0.7.

2.4 Learning environment research

Two broad categories of factors influencing learning are (a) attributes of the learner and (b) characteristics of the learning situation. One way of interpreting the learning situation is as a learning environment, which incorporates both. In this section, I will review research on classroom learning environments and the development of instruments that are now readily recognised. In addition, I will review an alternative method for assessing the nature or structure of technology-intensive learning environments.

I have already suggested that the Physics Studio learning environment was created along constructivist/social constructivist principles. However, it has been noted that teachers tend to be more positive in their assessment of their own learning environments (Wubbels & Brekelmans, 1998), especially when a "conceptual change, student focussed" approach is adopted (Prosser & Trigwell, 1997). Hence students' perceptions are likely to provide a more accurate, less biased, 'picture'. In addition, students have encountered many different learning environments and are in class for many hours and therefore have enough time to form an accurate impression of the classroom milieu (Walberg, 1976, cited in Moos, 1979).

Moos provides an overall perspective of a classroom 'climate'. See Figure 2.1

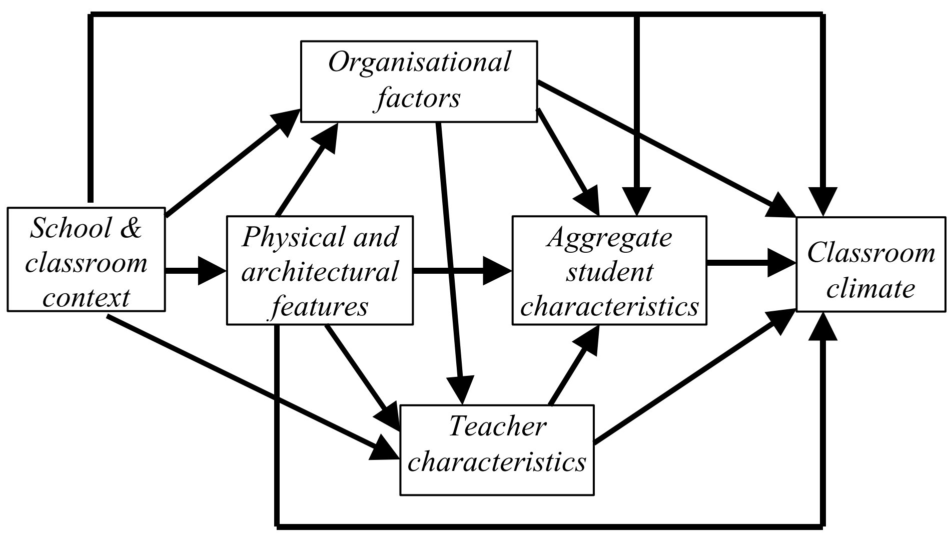

Figure 2.1. Model of the determinants of a classroom learning climate (Moos, 1979, p. 161)

Hence, factors which might be subject to measurement or assessment in evaluating a given learning climate or environment are:

- the physical setting;
- teachers' and students' characteristics and behaviours;
- teachers' and students' expectations and understandings;
- the learning tasks;
- the nature of the subject and content to be learned;

- teacher responsibilities.

For a constructivist learning environment, each of these must be viewed from a constructivist position. According to a constructivist view, meaningful learning is a cognitive process in which individuals make sense of the world in relation to the knowledge which they have already constructed, and this sense-making process involves active negotiation and consensus-building. Hence the learning tasks as well as the teacher's and students' expectations, understandings and behaviours in a 'constructivist' classroom are expected to be different from those in a more traditional classroom.

2.4.1 History of learning environment research

Learning environment research has been prominent over the last 30 years, in particular since about 1985. It grew out of the unrelated research programmes of R. Moos and H. Walberg. Walberg developed the Learning Environment Inventory to evaluate activities within the innovative, student-centred Harvard Project Physics course. R. Moos developed the Classroom Environment Scale, an instrument based on earlier work on assessment of the 'social climate' in psychiatric hospitals and correctional institutions. Since then, a number of instruments for assessing psycho-social environment have been developed (Fraser & Walberg, 1991).

Moos' three psychosocial dimensions of Personal Relationship, Personal Development, and System Maintenance and Change have been used as an organising framework for many of the instruments. Personal Relationship refers to how involved people are, how much they help one another and how they express their feelings. Personal Development refers to student independence and achievement. System Maintenance and Change refers to the orderliness of the setting, how clear the expectations of students, the nature and degree of control exercised by the teacher, and how responsive the system is to change.

More recently, classroom environment surveys, which investigate physically or psychologically different learning environments, have been developed. For a comparison of various science learning environment instruments, see Fraser (1998). There are surveys for assessing small group, laboratory or computer-based learning environments and others that investigate how students perceive classes designed along constructivist principles. Some surveys ask for students' personal or individual perceptions while others seek to uncover shared or group perceptions. There are also 'actual' and 'preferred' forms of many of these surveys, in which students either report on how they perceive their classroom to actually be, or how they would prefer it to be.

2.4.2 Importance of classroom learning environment research

The educational relevance of learning environment research has derived from Lewin's assertion that the environment and its interactions with the personal characteristics of the individual are powerful determinants of human behaviour {Lewin (1936) cited in Fraser (1998)}. The implication is that in classrooms, students' motivation and learning behaviours may be affected as much by the psychosocial environment as they are by teacher directions, teaching methods or the subject matter.

There are now many studies on learning environments that link students' positive perceptions of their learning environment with enhanced cognitive outcomes (Wubbels, Brekelmans & Hooymayers, 1991), positive attitudes to their class (Henderson & Fisher, 1998; Nair & Fisher, 1999) and enhanced student satisfaction (Fraser & Treagust, 1986). As Henderson and Fisher (1998) point out, a positive attitude is more likely to sustain interest in the field. As well, peers are influenced by the attitudes of others. In practical terms, teachers ought to be able to maximise students' learning outcomes by developing optimal learning environments.

2.4.3 Assessing learning environments

Different ways of assessing learning environments are from the point of view of a detached observer, termed *alpha press* or from the point of view of participants, termed *beta press*. Further to this, beta press can be *private* when the assessment is from an individual's perspective of how they are involved in the environment, and *consensual* when the assessment represents the shared view of the environment within members of the group. (Fraser, 1998). In addition, Fraser advocates an approach in which qualitative data, such as that yielded by interviews, observation or case studies, supplements that obtained through quantitative instruments.

The majority of classroom learning environment instruments are aimed at secondary students and/or their teachers, although a few of these have been modified for younger students. Each instrument consists of a number of scales, usually between five and eight, examining different dimensions of the learning environment. The dimensions are derived either through phenomenological research or from theory-based inferences. They have a four or five point response structure. Several of the well-known instruments available for use in secondary classrooms are the Classroom Environment Scale (CES), Constructivist Learning Environment Survey (CLES), and Science Laboratory Environment Inventory (SLEI).

Actual and Preferred forms

The actual form of a learning environment instrument asks students, or teachers, to describe the actual (experienced) environment. The preferred form asks for what teachers or students regard as the ideal environment. This might be shaped by the respondents' goals and value expectations and hence be at variance with what is being experienced. Students have been found to achieve better in their preferred classroom environment (Fraser, Treagust & Dennis, 1986).

A number of studies, which have incorporated both the actual and preferred forms of classroom environment instruments within the same investigation, have been described (Fraser et al., 1986). In these studies, it was found that both students and teachers preferred a more positive classroom environment than they perceived as being actually present and teachers tended to perceive the classroom environment more positively than did their students.

Personal and Class forms

Questionnaires which assess the whole-class environment assume that there is a unique learning environment in the classroom that all students in a class more or less experience The perceptions of a learning environment by a given individual may paint a very different picture. Students who are more involved in the learning experience tend to report more favourably on the environment (McRobbie, Fisher & Wong, 1998). As a result, *personal* forms of many of the classroom learning environments have been generated. These instruments ask students for their personal perception of *their role* in the environment of the classroom rather than their perception of the learning environment as a whole. Data provided by McRobbie et al show that students had a more positive view of the learning environment when they responded to the whole class survey than when they gave their perceptions of their own role in the classroom environment. These were not large differences but the direction was consistent among different samples.

2.4.4 Tertiary level learning environments

There is little published research on evaluation of classroom learning environments at the tertiary level, where most research has been at an institutional or school level. In the mid 1980s, the College and University Classroom Environment Inventory (CUCEI) was developed for use in small tertiary-level classes or seminars (Fraser & Treagust, 1986; Fraser et al., 1986) and later modified to a personalised format with two changed scales and a five-point rather than four-point response structure (Nair & Fisher, 1999). In the mid 1990s, the University Social Constructivist Learning Environment Survey (USCLES) was developed (Taylor, Fisher & Fraser, 1996).

University Social Constructivist Learning Environment Survey

The theoretical design of the instrument was based on a pedagogical interpretation of a social constructivist model of cognition. The interpretation is of a supportive classroom environment that engages students in both communicative and reflective learning activities. Communicative and reflective activities promote opportunities for

- making the subject ‘personally relevant’;
- enabling the teacher to assess the efficacy of teaching strategies;
- demonstration of care and concern for all students;
- students to admit to the uncertainty of their knowledge in a non-threatening situation; and
- students to consider all views and the possibility of more than one ‘correct’ answer.

Traditional teacher-centred classroom environments can assimilate a constructivist perspective but remain largely unchanged (Taylor, Fraser & Fisher, 1997) if teachers do not simultaneously adopt a different epistemology. Teachers must become mediators of students' encounters with their social and physical worlds and facilitators of students' interpretations and re-conceptualisations. The USCLES was designed to enable an assessment of the extent to which teachers were adopting a more (social) constructivist approach in tertiary classrooms.

The USCLES uses scales from two previously designed and validated instruments, the Constructivist Learning Environment Survey (Taylor et al., 1997) and the Questionnaire on Teacher Interaction or QTI (Wubbels et al., 1991). The QTI focuses on the nature and quality of interpersonal relationships between teachers and students. Wubbels and Brekelmans (1998) in a study of the teacher factor in the social climate of the classroom have shown that students' positive perceptions are better when teachers are 'cooperative' rather than 'oppositional', i.e. Understanding, Helpful/Friendly and Leadership behaviours are related positively to student attitudes. The same behaviours also resulted in better student cognitive outcome scores.

The first three USCLES scales, Relevance, Reflective Thinking and Negotiation are about opportunities for the teacher to engage students in communicative activity and reflective thinking – leading to deep conceptual understanding within the discipline. These scales were drawn from the CLES. The second three scales, Leadership, Empathy, and Support (or Helpfulness) are about the types of interpersonal qualities that need to be displayed by a university teacher in persuading students to transform their established epistemologies and approaches to learning to those are more in line with a constructivist epistemology.

Validation of learning environment instruments

The internal consistency, or reliability, of scales is normally reported using Cronbach's alpha coefficient. The higher the alpha coefficient, the more reliable or internally consistent is the scale. Discriminant validity is generally reported using the mean correlation of the scale with the other scales in the same instrument as a convenient index. The lower this value, the more likely it is that the dimension is independent of other dimensions. Both analyses are performed using the class as the unit of comparison. Finally, the ability of the instrument to differentiate between the perceptions of students in different classrooms is commonly reported as the eta^2 statistic (an effect size statistic) derived from an analysis of variance calculation. This represents the proportion of variance explained by class membership, and is performed using the individual as the unit of analysis.

Table 2.4. USCLES scales and sample items from actual and preferred forms – adapted from Table 1 (Taylor et al., 1996).

Scale	***Sample item Actual Form***	***Sample item Preferred Form***
Relevance*: perceived relevance of learning to students' own experiences, background knowledge and aspirations.*	*In this class, my learning focuses on issues that interest me.*	*In this class, I would prefer that my learning focuses on issues that interest me.*
Reflective Thinking*: perceived press for reflecting critically on background knowledge, new ideas and understandings, and role as a learner.*	*In this class, I learn how to become a better learner.*	*In this class, I would prefer that I learn how to become a better learner.*
Negotiation*: perceived press for communicating ideas with the teacher and other students.*	*In this class, other students ask me to explain my ideas.*	*In this class, I would prefer that other students ask me to explain my ideas.*
Leadership*: perceived leadership qualities of the lecturer, such as organization, setting tasks and holding attention.*	*In this class, the lecturer talks enthusiastically about his/her subject.*	*In this class, I would prefer that the lecturer talks enthusiastically about his/her subject.*
Empathy*: perceived way in which the lecturer shows understanding, listens attentively and show confidence in students.*	*In this class, the lecturer realises when students don't understand.*	*In this class, I would prefer that the lecturer realises when students don't understand.*
Support*: perceived extent to which lecturer assists, shows interest and inspires confidence and trust in students.*	*In this class, the lecturer is someone students can depend on.*	*In this class, I would prefer that the lecturer is someone students can depend on.*

2.4.5 An alternative approach to learning environment assessment

An alternative perspective on the assessment of learning environments is offered by Salomon (1996). This was prompted by the growing use of computers in classrooms – resulting in what might be termed technology-intensive learning environments (TILEs). Salomon argues that the incorporation of computers in classrooms has had a profound effect on the nature of student learning activities and teacher/student/student interactions. Incorporation of technology is not the sole source of changes in such learning environments but it makes many alternative strategies and interactions possible. Such changes include the reliance on group or pair work because of the (usual) need to share a computer terminal, computer-afforded activities such as model-building or testing, simulations or real-time data collection, display and analysis. In addition, the use of computers for different forms of communication is a change from the traditional ways of sharing information.

In Salomon's view, it is no longer viable to use traditional instruments to assess the social and learning environments of TILEs because it is simply not possible to isolate specific variables and measure them. Instead of the traditional focus on the learner and poorly isolated discrete input variables, he argues that we should be focussing on the whole learning environment. As yet, there is no viable theory which will allow simultaneous study of individual and environmental changes within the same conceptual framework. A possible solution is to change from an analytic approach to a systemic approach, that is to change from a study that looks at "patterns of differences" to one that examines "differences in patterns". In other words, instead of looking for systematic differences among individuals, the focus should be on characterising the entire environment and how it changes. In this way, pre and post instructional environments can be compared, or an experimental learning environment can be compared with a 'control' environment.

To graphically illustrate relationships within a TILE, Salomon proposes a multidimensional scaling technique. Multidimensional scaling (MDS) allows one to translate a set of correlations or other measures of association among scaled variables into non-metric (ordinal) distances among points and to locate each point relative to all others within a Euclidean space in such a way that is unaffected by the orientation or metric of the dimensions (Young, 1987). MDS can help to group data in areas where the organising concepts and underlying dimensions are not well developed. It represents objects which are experimentally similar to one another as points close to each other in a spatial map and objects which are dissimilar are represented as points distant from one another (Schiffman, Reynolds & Young, 1981).

Salomon employed an MDS variant called Smallest Space Analysis (SSA) – a technique developed by Guttman (1968) and now incorporated in many modern statistical analysis programmes such as SPSS. SSA usually employs two dimensions and maps variables as points whereby those close to the centre are more closely interrelated and those further out or peripheral share less in common with one another. As well, closeness in the map implies similarity or association and distance signifies difference or lack of association. This structure is termed a radex (Kruskal & Wish, 1978). Other structures or representations are possible.

Salomon demonstrates how such a technique might work by analysing the difference between the learning environments of an experimental TILE and a control group. He compared the 'patterns' obtained before and after the introduction of a computer-intensive curriculum and found that the TILE was characterised by a close relationship between individuals' learning and social interaction. Salomon also suggests that this conception of a learning environment assessment might not produce replicable or even interpretable results and should be the subject of much more investigation.

2.5 Epistemological beliefs

Personal reflection:

> *A colleague of mine once expressed exasperation about the attitude of one of her seventeen-year old Biology students. It was near the end of the year and examinations were looming. As a revision task for her students, she had selected a number of essay questions designed to help them integrate their ideas from several sections of the course. After discussing likely ways that they might go about the*

> *task, she was confronted by one student who suggested: "Instead of us all doing this separately, why don't you just write out the correct answers and we will learn them."*

At that time, I held only a loose conception of the importance of what that student was telling us about her beliefs about knowledge, knowing and role of the teacher in learning.

2.5.1 Introduction

In this section, I will review research on the nature of the construct of epistemological belief, the development of people's epistemological beliefs, and the effect that different beliefs might have on learning, in particular, physics learning.

Epistemological beliefs are beliefs that people have about knowledge and knowing – what knowledge is, and what it means to know and to build knowledge. The role of students' epistemological beliefs as mediators of learning is being increasingly investigated. For an overview see Hofer and Pintrich (1997). A growing body of evidence is now demonstrating the positive effects of more sophisticated beliefs on students' motivation, use of appropriate learning strategies and academic achievement.

What emerges is that research on epistemological beliefs is tenuous, often based on hypothesis and incomplete or equivocal data. There is only partial agreement on the meaning and scope of the construct, and measurement is difficult and error-prone. While the existence of strong beliefs about knowledge and learning is not questioned, it is not clear whether these beliefs form, or are part of, a coherent set of developmental stages or whether they are simply facets or dimensions of knowledge. A further issue is whether such beliefs are domain dependent i.e. whether they find expression within specific subject contexts. Because of such difficulties, this, and indeed any research on epistemological beliefs, must be based on some assumptions and a somewhat tentative research base.

2.5.2 Historical research and theory development

Psychological research into epistemological beliefs and learning over the last 30 years has progressed almost simultaneously along three lines:

1. How individuals interpret their educational experiences;
2. How epistemological assumptions influence thinking and reasoning processes; and
3. How epistemological beliefs may influence students' comprehension and cognition for academic tasks.

The first line of research has many documented examples, notably beginning with the seminal work of William Perry (1970). See also Baxter Magolda (1992) Belenky and Clinchy (1986), King and Kitchener (1994) and Schommer (1990) The second and third are on-going lines of research with subjects ranging from primary students through to adult learners. Such research has generated interest among education researchers since it is generally hypothesised that aspects of students' learning may depend on, and/or change, their epistemological beliefs. The third line of research has taken the approach that epistemological beliefs do not form a single coherent structure but are a series of more or less independent dimensions.

Perry used a phenomenological approach to gather and interpret the epistemological views of university undergraduates, producing a 'scheme of intellectual and ethical development' of college students. Perry used the term 'positions' to describe students' opinions about the nature of knowledge and truth. See Table 2.5. In particular, he probed the ways that students view themselves and their learning, how they make meaning of their world, how they interpret and make sense of the classroom environment, how they view knowledge and the process of learning, and how they understand the roles of the teacher and students in this process. He hypothesised that students proceed through an invariant set of developmental stages, moving from a simplistic or absolutist stance on the fundamental nature of knowledge, through to a complex, pluralistic perspective. He identified nine epistemological positions in four categories. The normal progression however, can be interrupted in different ways that Perry called retreating (to a safer, more conservative position), temporising (delaying progress) and escaping.

Perry also suggested that how college students made meaning of their educational experience was not a reflection of personality but an evolving developmental process.

Table 2.5. Perry's (1970) stages of intellectual and ethical development and epistemological positions.

Category	Positions
Dualism	1. Knowledge has a polar nature i.e. right or wrong, good or bad. Right answers to problems exist; and it is the role of 'Authority' to teach them. Exams quantitatively test for 'right answers'. 2. Diversity or uncertainty of opinion are seen as unwarranted and related to poorly-qualified authorities – or exercises set by authority so that students can find the right answer for themselves.
Multiplicity	3. Diversity and uncertainty are accepted as legitimate but temporary – where the right answer has yet to be found. 4. Uncertainty and diversity of opinion are legitimate, as all views are valid, but Authority still operates in a right/wrong system. There is a knowable truth vested in Authority. Qualitative contextual reasoning is seen as a special case.
Relativism	5. All knowledge and values, including Authority's, are contextual and relativistic. Right/wrong has the status of special case. 6. There is a necessity for personal commitment rather than unquestioned, simple belief in certainty.
Commitment within relativism[a]	7 – 9. These positions involve implications of commitment and responsibility, and affirmation of identity among multiple responsibilities.

[a] *These positions are less explicitly epistemological than lower positions. Perry did not identify them in undergraduate-level students.*

2.5.3 Defining the construct of epistemological beliefs

Two of the problems that have beset research on epistemological beliefs have been the lack of consensus about the name, definition and delineation (or boundaries) of the construct and the nature of the construct under study (Hofer & Pintrich, 1997).

Naming and defining the construct

Different researchers use labels such as epistemological attitudes, assumptions, positions, beliefs, standards or resources for what appears to be the same construct. Hofer and Pintrich's useful comparison of the various research programs that have succeeded Perry's, illustrates this variation:

Women's ways of knowing

Research into feminist beliefs – or at least a female perspective on epistemological beliefs. The work of Belenky et al (1986) centred on women's opinions because of the criticised absence of women in Perry's college sample – but their focus was more on the *source of knowledge* rather than its nature or veracity. They use the terms *epistemological commitment* and *perspectives*.

Epistemological reflection model

Baxter (1992) investigated students' views about the roles of the learner, instructor and peers in learning, as well as the nature of knowledge and decision-making. This view of epistemological beliefs is more about the *nature of learning* and the *justification for knowing* as situated in the college classroom context rather than purely on assumptions about knowledge itself.

Reflective judgement model

King and Kitchener (1994), drawing on Dewey's work on reflective thinking as well as Perry's scheme, focused on 'epistemic cognition' – ways that people understand the *process of knowing* and the corresponding ways they justify their beliefs about ill-structured problems i.e. the *process of justification of knowledge*. Their work assumes a developmental stage structure of beliefs. They argue that reflective judgement is an ultimate outcome and developmental endpoint of reasoning and the ability to evaluate knowledge claims.

Argumentative reasoning

Kuhn (1993) links epistemology with reasoning, suggesting that the skills of argument require higher levels of epistemological understanding. Such processes require students to be metacognitive about their own thinking. She identifies students' arguments based on assumptions about *certainty of knowledge*, *justification for knowing* and *source of knowledge*.

Epistemological beliefs

Schommer takes a more analytic view of the components of epistemological beliefs, and has reconceptualised personal epistemology as not one, but a series of more or less independent dimensions, consisting of the *structure, source* and *certainty of knowledge*, and the *control* and *speed of knowledge acquisition*.

Structure of the construct

A second issue that remains unresolved is that of the form or structure of epistemological beliefs. Perry (1970), Ryan (1984), and King and Kitchener (1994), assume a hierarchical, stage-like developmental structure. If this type of developmental scheme is 'Piagetian' in nature, then change is brought about through cognitive disequilibrium. Individuals interact with the environment and respond to new experiences by either assimilating new beliefs to existing cognitive frameworks or accommodating the framework itself.

Schommer offers an alternative model, suggesting that different facets or dimensions of beliefs might be considered independent (orthogonal) in that they do not have to form a single coherent structure. Students might be sophisticated in some beliefs but more naïve in others. This proposal is inconsistent with a stage-like development of a single belief structure, but does not preclude the process of change through cognitive disequilibrium.

After considering the various theories and models of epistemological beliefs, and to enable future research to at least work from a common base of assumptions, Hofer and Pintrich suggest that:

1. The core content of the construct of epistemological beliefs be limited to individual's beliefs about the *nature of knowledge* (consisting of *certainty of knowledge* and *simplicity of knowledge*) and the *process of knowing* (consisting of *source of knowledge* and *justification for knowing*) thus omitting 'peripheral beliefs' related to learning, intelligence and teaching.
2. Epistemological beliefs be considered as 'personal theories', which are neither strictly stage-like, nor are they independent of one another. Personal theories (Wellman, 1990) have the following characteristics: coherence among constituent ideas and concepts; ontological distinctions between certain entities and processes; and a causal-explanatory framework for phenomena in the domain.

While both of these restrictions may be useful in the investigation of epistemological beliefs as an object of study, they are not particularly useful in the study of epistemological beliefs within an education application.

Two of Schommer's belief dimensions fall outside the definition of epistemological beliefs suggested by Hofer and Pintrich. Individuals' beliefs about *structure, source* and *certainty of knowledge* are consistent, however, individuals' beliefs about the *control* and *speed of knowledge acquisition* are not. Hofer and Pintrich regard these beliefs as goals or motivation and term them 'peripheral beliefs'. In a similar way, a number of 'beliefs' related to the *roles of learner, peer and instructor* as well as *evaluation of learning*, identified by Baxter Magolda, are classified as peripheral beliefs. While these research-based models of Baxter Magolda and Schommer include beliefs that are outside a mainstream definition of epistemological beliefs suggested by Hofer and Pintrich, they are ones more likely to provide a useful framework for investigating student learning. They may also prove more useful in providing further insight on the responses of students to particular learning environments.

2.5.4 Assessing epistemological beliefs

The methods used to elicit people's epistemological beliefs in the first instance were phenomenological. However, cost, time and complexity of interpretation caused other researchers to develop pencil and paper methods, which generally involved people responding to written questions or commenting on different scenarios. See for example the Measure of Epistemological Reflection (Baxter Magolda, 1992). For most methods, trained raters or interpreters are needed to translate and classify students' interview transcripts or written words into various epistemological positions. This alone makes it difficult to accomplish for large cohorts, particularly where it is not the nature of the construct that is under investigation, but an investigation of some other parameter that may interact with epistemological beliefs.].

In contrast to the above methods, Finster (1989a; 1989b), Katung, Johnstone and Downie (1999), Ryan (1984) and Schommer(1990) developed more easily administered questionnaires based on students' ratings of different statements using a Likert scale (or similar). Whereas Ryan, Finster and Katung et al based their questions directly on Perry's model, Schommer based hers on Perry's model as well as research on perceptions of intelligence by Dweck and Leggett (1988) and learning in mathematics by Schoenfeld (1983). Questionnaire methods make assessment of beliefs of a large student cohort much easier to accomplish.

The Schommer instrument, which I selected for use in this study, will be discussed in more detail in Section 2.5.13, together with further reasons for choosing it.

The nature of beliefs, attitudes and the status of belief versus knowledge are covered in Section 2.6.

2.5.5 Acquisition and change of epistemological beliefs

How do ideas about knowledge and knowing become part of people's thinking and how do they change?

From a Piagetian or developmental model, the trigger might be a form of cognitive disequilibrium. As discussed previously, disequilibrium results in cognitive change – either assimilation where the new knowledge is incorporated without a major structural change, or accommodation in which new knowledge structures are generated. Presumably this might occur if a student 'discovered' that a new way of learning proved to be superior to a more accustomed method, which was supported by different epistemological belief.

This type of reasoning is not unlike that suggested in the literature for promoting conceptual change. It is also possible that different contexts for learning, changing subjects, changing teachers or changing from high school to university may prompt changes in a student's beliefs by exposing them to alternative viewpoints about knowledge and learning.

Along this same line, it is not known how resistant epistemological beliefs are to change. Schommer (1993) suggests that teachers inform students about knowing and its consequences in a particular discipline. However, as Hofer and Pintrich point out, teachers may tell students about ways of knowing in a subject, while implementing practices that contradict this. A teacher may say that science values deep thinking and creative problem solving, but if he/she then assesses students' knowledge using relatively low-level multiple-choice tests, those students may learn that knowledge in science really is 'simple'.

In general, the more advanced the education, the more sophisticated the beliefs (Jehng, Johnson & Anderson, 1993; Schommer, 1993, 1998; Schommer, Calvert, Gariglietti & Bajaj, 1997), which suggests that beliefs do change, and are related to level of education. A longitudinal study by Schommer et al (1997) and Schommer (1993) found that students' beliefs in *fixed ability to learn*, *simple knowledge*, *quick learning*, and *certain knowledge* changed over a four-year period in high school. In each of the four dimensions, students' beliefs, on average, became less naïve.

2.5.6 Epistemological beliefs in society

All researchers investigating epistemological beliefs envisage peoples' beliefs changing from some sort of naïve or less developed position, seen commonly in young children, to an ultimate high level, advanced or sophisticated position, which may be attained by only a small percentage of the population. The definitive descriptors used to outline knowledge from a naïve perspective are terms such as right/wrong, black/white, truth, authoritarian, absolute and unambiguous. These terms are also associated with an objective, empiricist view of the world. Descriptors used to outline knowledge from more sophisticated positions, such as relativistic, independence, interrelatedness and personal meaning are more aligned to a constructivist view of the world. Roth and Roychoudhury (1994) described physics students' naive epistemological beliefs as objectivist, and more sophisticated views as constructivist, according to the metaphors that they used to describe knowledge and knowing.

Students' epistemological beliefs are likely to reflect the beliefs and behaviours of parents, teachers and society in general, towards knowledge and knowing. Large sections of western society, noticeably males support an authoritarian view of knowledge and learning, acceptance of an ultimate truth and the investiture of knowledge in experts (Longino, 1999). Other sections, and perhaps more noticeably among women, support a more subjective or contextual view of personal knowledge even though the formal place of experts in society is accepted. It seems reasonable to assume that teachers, as members of society, by and large adopt teaching practices that are generally consonant with the ideals of their society.

2.5.7 Epistemological belief change

As suggested earlier, it is possible that changes to epistemological beliefs can be likened to conceptual change. An early conceptual change model (Posner et al., 1982) described necessary conditions for conceptual change – dissatisfaction with an existing conception, and adoption of a new conception provided it is plausible, understandable and fruitful. Later models take into account the learners' 'conceptual ecology', resources, motivation and metacognition, as a mediator of change. Change involves a change in cognitive structures. Some changes are simply accretionary – involving addition of new concepts to the existing structure. These changes can also serve to strengthen existing knowledge or beliefs. Sometimes the new knowledge is incompatible with existing structures so that meaningful learning requires a more fundamental alteration of conceptual structures. Such permanent change is more difficult to effect – and this is often associated with conceptual change learning in physics.

Changes in epistemological beliefs may involve a similar process. If beliefs form a knowledge framework for making judgements or decisions about learning, new knowledge may serve to strengthen the framework. If a new view of knowledge or knowing is incompatible with the existing framework, then there must be a cognitive restructuring or, if not, the new idea will be rejected. Teaching strategies or learning activities that require students to work in more constructivist ways, that appear to validate such ways of working AND that led students to learning success may provide sufficient impetus for effecting change. This hypothesis was important in framing the research questions for this study.

2.5.8 Domain dependence of epistemological beliefs

The role of domain differences in epistemological thinking has had little formal investigation. Domain is taken to mean academic discipline. An initial issue to be resolved is whether or not epistemological beliefs are 'domain-dependent', that is, whether different beliefs are reserved for different subjects. Do learners believe physics knowledge is different from knowledge in other subjects? Is knowledge in physics, for example, right or wrong and handed down from authority (lecturers or books) but knowledge in history relative and constructed by the learner? A second issue is whether students with particular beliefs are pre-disposed to select certain major subjects, particularly at the tertiary level, or is it the subjects or related contextual factors that mould or shape students' epistemological beliefs?

Paulsen and Wells (1998) investigated the issue of whether there were differences in epistemological beliefs of students across different academic disciplines. This was carried out in response to previous contradictory findings of other researchers. Jehng et al (1993) found that the epistemological beliefs of college students with majors in humanities, arts and social sciences were more sophisticated than those of student with majors in engineering and business, even after controlling for educational level. Schommer (1993) found that students enrolled in educational psychology were less sophisticated than those of technological science majors. However, when Schommer and Walker (1992) compared the epistemological beliefs of college students in mathematics and the social sciences, they found "moderate" but not "strong" support for domain-independence.

To try to resolve this apparent inconsistency Paulsen and Wells (1998) sought to uncover any links between the major academic disciplines and students' epistemological beliefs. They used Biglan's (1973) classification scheme of university disciplines. Six disciplines (humanities and fine arts, social sciences, natural sciences, education, business and engineering) were classified on two orthogonal continua: *hard-soft* and *pure-applied*. The *hard-soft* dimension refers to the degree of paradigmatic development of the field and the *pure-applied* dimension refers to the degree which a field emphasises applications to practical problems. Engineering, for example, was classified as *hard-applied*

Students majoring in *pure* fields (including physics) were more sophisticated in their beliefs than students majoring in *applied* fields (including engineering). When the separate dimensions are considered, students majoring in *applied* fields are significantly more likely than students majoring in pure fields to hold naïve beliefs about Simple Knowledge, Quick Learning and Certain Knowledge. Students majoring in *hard* fields are significantly more likely than those majoring in *soft* fields to hold naïve beliefs in Certain Knowledge.

One reason offered is that faculty in soft fields are more likely than those in hard fields to (a) use discursive student-centred approaches, (b) ask questions and call for analysis and synthesis and (c) include critical thinking questions on their examinations. Each of these reinforces the view that knowledge is diverse, tentative and open to change.

> *Beliefs that knowledge is absolute, certain, and unchanging, rather than tentative and evolving, may be encouraged or reinforced to some extent by a primary contextual feature of hard fields – that there is a high degree of consensus among scholars regarding the content and methods of the field. This consensus may communicate to students that knowledge is certain due to the various ways it is presented in classes and textbooks.*
>
> (Paulsen & Wells, 1998, p. 377)

Paulsen and Wells also suggest that equivocal earlier findings of Schommer and Walker may relate to their domain classification criteria. Although mathematics and the social sciences are different academic domains, according to the Biglan scheme, they are both *pure* fields. Hence, students may be sufficiently similar in epistemological beliefs to lead researchers to the conclusion of domain-independence.

Domain-dependent beliefs are more easily conceived if epistemological beliefs form separate dimensions rather than a general set of beliefs. This allows not only for beliefs to be at different levels of sophistication, but also for the same belief to be expressed differently in different contexts. It seems plausible that in situations of uncertainty, or when faced with challenging problems of difficult material to learn, students may regress or revert to lower levels or naiveté in their beliefs in relation to that subject. If they have not felt in control of their learning, or have been obliged to behave towards or learn a particular subject in a particular way, students may develop beliefs about knowledge and knowing in that subject, which are transient, temporary or conditional.

Support for this position is provided by Kardash and Scholes (1996) whose study of the influence of people's epistemological beliefs on their interpretation of controversial material led them to conclude that both general and topic-specific beliefs contributed independently to the conclusions people drew from what they read. They also suggest that people habitually approach complex and challenging tasks in certain ways that also contribute to their interpretation of inconclusive and mixed evidence.

Perry (1970) posited that students may retreat to lesser levels of beliefs when faced with harder tasks. This may explain some of the evidence for beliefs being domain dependent. Physics and mathematics are conceptually difficult subjects, hence for many students lesser beliefs, and what that entails for learning, may well be the default position.

2.5.9 Epistemological beliefs and the process of learning

What is the link between epistemological beliefs and the process of learning? Perry has suggested that changes in students' views of the nature of knowledge and the role of authority will lead to observable changes in manner of studying. Other researchers (Hofer & Pintrich, 1997; Roth & Roychoudhury, 1994; Säljö, 1987; Schommer, 1993; Schommer et al., 1997) propose that there are a variety of motivational attitudes and behaviours and individual characteristics that mediate between a student's epistemological beliefs and intellectual performance. It is likely, however, that some of these attitudes are shaped or moderated by students' beliefs. The process of cause and effect is unclear.

Motivational factors in learning

Hofer and Pintrich (1997) refer to two exploratory studies in which attempts have been made to link epistemological beliefs with motivation and cognition. They cite Schutz, Pintrich and Young (1993) who found that college students who were more sophisticated toward knowledge were more likely to adopt a mastery-learning goal and to engage material more deeply. They also cite Hofer (1994) who, in a study of first year calculus students, found a strong positive correlation between sophistication of mathematics-related epistemological beliefs and intrinsic motivation, self-efficacy, self-regulation and academic performance.

2.5.10 Epistemological beliefs and academic performance

Many children, in their primary school years, believe that intelligence is fixed and that intelligence alone determines academic performance (Stipek & Gralinski, 1996). Primary school students' beliefs about intelligence were found to affect their goals for learning; different goals (performance goals or learning goals) led to different patterns of learning (Dweck & Leggett, 1988). When faced with a difficult task, those who believed in fixed intelligence gave up early, saying that the task was too hard. Children who believed in variable intelligence were more inclined to persist in their efforts and to change learning strategies, and they outperformed those with fixed-intelligence beliefs.

Bendixen et al (1994) also suggest that high school students' naïve beliefs in fixed ability may predispose them to develop academic goal orientations based on assumptions about the malleability of intelligence. Using Schommer's questionnaire, they found that students' epistemological beliefs were related to their levels of reflective judgement, determined using Kitchener and King's Reflective Judgement Scale. They suggest that students who view ability as fixed may be less inclined to pursue challenging intellectual experiences or tackle intellectual tasks strategically and so may be less inclined to develop and utilise sophisticated reasoning skills when thinking about ill-defined dilemmas.

Pintrich, Marx and Boyle (1993) talk about 'self-efficacy beliefs' which they do not acknowledge as deeply epistemological but rather students' judgements about their cognitive capabilities to accomplish a specific task or obtain specific goals. They assume self-efficacy beliefs to be relatively situation-specific, not global personality traits or general self-concepts. It is possible that measurements of students' beliefs about innate ability, or fixed intelligence and its effect on achievement, may be tapping into this more surface-level belief. It is also possible that the deeper epistemological belief is expressed as self-efficacy when applied to or within a particular context.

A possible link between epistemological beliefs and performance is provided by Schommer et al (1997, p. 38):

> *If a teacher tells a student to 'study for a test' without further specific instructions, the students' dominant epistemological beliefs will serve as a guide to studying. If students strongly believed that knowledge is characterised as integrated concepts, they would look for connections between concepts in the text and with their prior knowledge. Once they were able to compare and contrast numerous concepts, the students would believe that they were ready for the test. On the other hand, if they strongly believed that knowledge is best characterised as bits and pieces, they would select a study strategy that would allow them to memorise lists of facts. Once they were able to recite the list of facts, they would believe that they were ready for the test. Indeed, epistemological beliefs may be so strong that students are resistant to any specific advice that the teacher may suggest.*

A further issue is the self-defeating nature of epistemological beliefs. Students may perform to standards that they perceive as appropriate, but if their perceptions of knowledge are simplistic, then the higher the education they pursue, the less adequate will be their learning. This has also been demonstrated more recently by Kember (2001).

Students' beliefs must change before the beliefs prove disabling. For example, Schommer (1990) found that epistemological beliefs appear to affect the critical interpretation of knowledge:

> *… it was not a question of students' being able to recall prominent information … but rather of what they concluded from the information. When one encounters material that is tentative, strong beliefs in certainty of knowledge leads to the distortion of information in order to be consistent with this belief* (p. 503).

For physics, complex theories are tentative but students do need to engage with the material at a level that leads to understanding premises and developmental arguments, rather than to try to adopt a rote-learning approach.

2.5.11 Students' beliefs about learning physics

A number of studies have attempted to investigate student epistemology in relation to physics. Phenomenological studies by Hammer (1994; 1996) and Roth and Roychoudhury (1994) have documented students' beliefs about how physics knowledge is structured and what learning in physics entails. Gunstone (1995) also describes situations in which physics students' beliefs that high intelligence and a 'good memory' are basic requirements for learning physics.

Hammer, in interviews with students involved in a hands-on, activity-based year 11 physics course, developed the following framework of students' beliefs about the *nature of physics* and of *learning physics* in order to classify students according to their beliefs.

Beliefs about the structure of physics

pieces ------------------------ weak coherence ------------------------ coherence

Beliefs about the content of physics

formulas ---------------Apparent and/or weak concepts ------------- concepts

Beliefs about learning physics

by authority --- independent learning

Hammer's category of *weak* (as in weak coherence and weak concepts) refers to students' beliefs that the structure and content of physics is coherent and conceptual respectively, but it is not important for them to know about it. This knowledge is the business of experts. *Apparent concepts*, are formalisms; beliefs about the content of physics that, to students, seem to be obvious in the sense that they need no description.

The first and third of these beliefs about physics are consistent with Schommer's (1990) proposed dimensions related to the simplicity and source of knowledge respectively, and hence are not necessarily dependent on the subject matter. Although the second belief might be subsumed within simplicity of knowledge, the view of physics consisting of formulas or concepts is more definitely domain-dependent.

Roth and Roychoudhury investigated students' views about the nature of scientific (physics) knowledge and their preferences for learning physics. They observed that students simultaneously held contradictory, or at least conflicting, views about the nature of scientific knowledge. When asked about the nature of scientific knowledge, most (75-81%) students responded with an objectivist epistemology (i.e. that scientific knowledge is factual, correct and true, and reflects nature) rather than a constructivist/relativist epistemology (i.e. that there are multiple views and no absolute truth). Students' views, however, changed to a more relativist/constructivist position when they were asked about, or talked about, presuppositions of, and social influence on, scientific knowledge. For these students, objectivism seemed to be the 'default epistemology'.

Students see physics knowledge as mathematical and conceptual (found in textbooks) and experiential (rooted in everyday and laboratory experiences). Mathematics is seen as an obstacle to understanding physics but at the same time, is regarded as useful because it provides a link with physics concepts, and is grounded in truth. Concepts are to be learned, are logical and not the same as everyday thinking – and hence not real. Students believe that the experiential nature of physics makes it useful and powerful. However, while they expressed a preference for un-structured and open laboratory work, they were still concerned with the 'right way of doing things'.

When referring to learning about science, students used objectivist metaphors. Teachers are seen as authoritative possessors of knowledge who transfer that knowledge to the minds of students. Roth and Roychoudhury identified five categories of metaphors used by students; knowledge as a material substance that can be transferred, minds as containers, knowledge as territory, brain as muscle (requiring practice and exercise) and knowing and learning as construction (building).

Metaphors are not simply a matter of language; they are the very foundation of our conceptual system with which we think and act {(Arbib & Hesse, 1986); Lakoff & Johnson, 1980, cited in Roth and Roychoudhury (1994)}. If this is so, then these students clearly understood physics/science as truth, known by more expert 'others' and loaded into their minds in a type of passive transferral. However, Roth and Roychoudhury were unable to identify individuals with a single epistemology. All used metaphors that were incommensurate with other epistemological positions. As a result, they suggest that beliefs about physics are more appropriately referred to as epistemological positions within a specific context rather than part of coherent theories. They also suggest that if science is presented to students as a body of knowledge, proven facts and absolute truths, then students will focus on memorising facts and think that knowledge can be ascertained through specific proof procedures embedded in the scientific method. If, on the other hand, students experience science as a continuous process of concept development, an interpretive effort to determine the meaning of data and a process of negotiating these meanings among individuals, then students might focus on concepts and their variations.

Hence it appears that beliefs about the nature of knowledge and process of knowing in physics reflect the early positions described by Perry. Many of Roth and Roychoudhury's students were dualists when it came to physics and mathematics, but some were more relativist when talking about the justification for knowing. While about half the students maintained that science cannot be based on presuppositions because it is based on exact and observable facts, others were more prepared to concede that societal influences could shape the content of scientific knowledge. This research supports the notion that beliefs may be domain dependent, and also that students may adopt more sophisticated epistemological positions in different contexts. The role of a higher knowledge authority seems unquestioned.

In a cross-country, comparative study of students and instructors (professors) in first year university physics, engineering and psychology, Donald (1994) found that the views and perceptions of physics students and their instructors differed more widely than for the other two disciplines. The physics instructors and students appeared to have different goals for learning and beliefs about the learning process. The more divergent views of physics knowledge of physics professors and students are contrasted in Table 2.6. It seems likely that the beliefs of students have been shaped by their high school experiences and that they have maintained their beliefs into their tertiary course.

Table 2.6.Physics professors' and students' contrasting views of physics knowledge.

Professors' views of physics knowledge	**Students' views of physics knowledge**
1. Professors' approaches to physics knowledge are highly intellectual, even at the introductory level.	1. Students have variable perceptions of how much physics they learnt in high school.
2. Knowing physics requires developing critical skills in solving novel situations.	2. High school teaching/learning activities are seen to mirror those at university.
3. Physics is a very highly disciplined thought process that has strict connections with logic and mathematics.	3. Learning physics is equated to success in problem-solving.
	4. Physics requires applying knowledge to unfamiliar situations
	5. What is 'known' is 'true'.

Donald (p. 93) offers some reasons for the divergent views of instructors and students in physics:

> *… the learning task in physics is difficult due to the sheer weight of the theory, and the fact that it is often counter-intuitive. This means that the learning pattern of students is intensive, requiring concentration to re-structure knowledge… … Professors take a highly intellectual, content-oriented view to instruction … [and] … equate problem-solving skills with evaluation of learning … …*

Students tended to think of learning in the course as a matter of acquiring knowledge, perhaps because they recognised their own inadequacies in the knowledge structures needed to solve problems.

2.5.12 Physics-related epistemological beliefs

Physics education researchers are also interested in students' beliefs about knowledge and learning, and their conceptions of science and the role of scientists (Hammer, 1994, 2000; Redish, Saul & Steinberg, 1998; Songer & Linn, 1991; Tobias, 1990; van Aalst & Keys, 2000). In particular, the interest has focussed on how students' beliefs may affect their performance in introductory physics courses at the college/university or high school level.

In physics education research literature, students' beliefs about knowledge are not always referred to as epistemological beliefs. The general assumption is that the beliefs are somewhat context dependent i.e. they are attitudes, beliefs or assumptions specifically about scientific knowledge and how it is generated, learning in science/physics classes, and the role of instructors or scientists in teaching students about science/physics. As a result, these beliefs are also called *epistemological resources* (Hammer, 2000) or *epistemological commitments* (Hewson, 1985; Roth & Roychoudhury, 1994). As with psychology-based research, there is no agreement about the nature of the construct.

Maryland Physics Expectation survey

Redish et al (1998) assert that students' epistemological beliefs, attitudes and assumptions lead them to have expectations about the structure of physics knowledge, how physics classes will be taught and how they will learn physics. If these expectations are not congruent with those of instructors or more advanced others in the class, students may not respond productively to courses, particularly those featuring innovative practices. In an attempt to measure and determine the effect of students' beliefs, Redish et al devised a 34-item, Likert–style questionnaire called the Maryland Physics Expectation survey (MPEX). A survey was selected because of the difficulties associated with large-scale qualitative assessments.

The MPEX survey tests for six types of belief. The first three were drawn from Hammer's (1994) work with six high school physics students (described previously) and the authors devised the last three. The six beliefs are:

1. *Independence* – beliefs about learning physics – whether it means receiving information or involves an active process of reconstructing one's own understanding.
2. *Coherence* – beliefs about the structure of physics knowledge – as a collection of isolated pieces or as a single coherent system.
3. *Concepts* – beliefs about the content of physics knowledge – as formulas or concepts that underlie the formulas.
4. *Reality Link* – beliefs about the connection between physics and reality – whether physics is related to experiences outside the classroom or whether it is useful to think about them together.
5. *Math Link* – beliefs about the role of mathematics in learning physics – whether the mathematic formalism is just used to calculate numbers or is used as a way of representing information about physical phenomena.
6. *Effort* – beliefs about the kind of activities and work necessary to make sense out of physics – whether they expect to think carefully and evaluate what they are doing based on available materials and feedback or not.

Data analysis

The brief descriptions above indicate the extremes of each view – favourable and unfavourable. The favourable view is that of 'experts', determined by the responses of "a majority of experienced physics instructors who have a high concern for educational issues and a high sensitivity to students" (p. 215).

Although students respond on a five-point scale (strongly agree – strongly disagree), for the purpose of analysis, both positive responses are grouped as 'agree' and both negative responses are grouped as 'disagree', so that there are effectively three responses – agree, disagree and neutral (or no answer). Different classes or courses of students are compared by comparing their ratio of favourable to unfavourable responses or by charting the responses on an 'A-D plot'. An A-D plot has % of favourable responses (A) on one axis and % of unfavourable responses (D) on the other and represents classes by a point in the triangular space. Different classes are then compared by their closeness to the ‘expert’ group, which is near the extreme corner of the plot. In general, the experts’ ratio of favourable to unfavourable averaged about 90%.

The MPEX has been used in a number of institutions in the USA and Canada in more of an exploratory manner than a regular testing programme. In the study conducted by Redish et al, calculus-based physics classes in six different tertiary institutions were given the survey as a pretest and posttest. Two observations were:

1. The initial state of the students at all universities tested differs substantially from the expert results …Beginning students only agreed with the favourable (expert) responses about 50% - 60% of the time … students explicitly supported unfavourable positions about 15% - 30% of the time.
2. In all cases, the result of instruction on the overall survey was an **increase** in unfavourable responses and a decrease in favourable responses (although some changes were not significant). **Thus instruction produced an average deterioration rather than an improvement of students’ expectations** (emphases added).

Similar observations were reported by van Aalst and Keys (2000) in Canada. Students in different physics courses at the same institution were compared. The groups involved were in the following classes: beginning physics, physics for life sciences, physics for engineers and honours physics. Overall, congruence with expert expectations decreased slightly, although there was a small positive increase on the *independence* set (which related to authority-based knowledge). There were a number of contradictory sets of responses between different physics classes, which lead the researchers to conclude that the context of learning i.e. a programme in the physical sciences compared with one in the life sciences, must be taken into account in research on students’ beliefs about learning physics.

2.5.13 Schommer's model of epistemological beliefs

In the 1980s, Schommer noted the inconsistent results of different researchers investigating students' epistemological beliefs. As a result, Schommer hypothesised that the idea that personal epistemology is a single, coherent set of beliefs is unlikely. Instead, she suggested that it is more probable that epistemological beliefs are a system of more or less independent beliefs. By system, she means that there are multiple beliefs to consider. By 'more or less independent' she means that students beliefs are not necessarily at consistent levels of sophistication with one another.

Schommer constructed a questionnaire designed to test for the existence of five hypothesised dimensions of epistemological beliefs. See Table 2.7. It consists of 63 short statements that characterise five different dimensions of epistemological beliefs. The five dimensions hypothesised by Schommer are beliefs in (stated from the naïve perspective): *knowledge* is *simple*, *certain* and *handed down by authority*, *learning* is *quick* and *ability to learn* is *fixed (*or *innate)*. Students rate the statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Table 2.7 Schommer's hypothesised system of epistemological beliefs.

Epistemological belief	**Naïve belief**	**Sophisticated belief**
Certainty of knowledge	Knowledge is absolute and unchanging.	Knowledge is tentative and evolving.
Simplicity of knowledge	Knowledge consists of isolated, unambiguous bits.	Knowledge consists of highly interrelated concepts.
Source of knowledge	Knowledge is handed down from authority.	Knowledge is derived from reason.
Quick learning	Learning occurs quickly or not-at-all.	Learning is a slow, gradual, developmental process.
Innate ability	The ability to learn is fixed at birth and cannot be changed.	The ability to learn is not fixed and can be changed.

For the first three dimensions, she drew on Perry's research. For the latter two, she drew on the work of both Schoenfeld (1983) (students' beliefs about learning mathematics) and Dweck and Leggett (1988)(students' beliefs about intelligence). Schommer proposed that these five belief facets or dimensions exist on a continuum from naïve to sophisticated and they are named from the naïve perspective. It is possible for students to be naïve in some of these dimensions and more sophisticated in others. The five beliefs and their naïve and sophisticated extremes are detailed in Table 2.8. She also states that these beliefs should not be viewed as dichotomies, but more accurately conceived of as frequency distributions.

Table 2.8 provides a summary of the overall scheme of the initial questionnaire. The full questionnaire can be found in Appendix 8.1.5.

Table 2.8. Overall scheme of the epistemological questionnaire and sample items.

Subset dimension	**Sample item**	**Nº of items**
Seek single answers Avoid integration	**Simple knowledge** Most words have one clear meaning. When I study, I look for specific facts.	11 8
Avoid ambiguity Knowledge is certain	**Certain knowledge** I don't like movies that don't have an ending. Scientists can ultimately get to the truth.	5 6
Don't criticize authority Depend on authority	**Omniscient Authority** People who challenge authority are over-confident. How much a person gets out of school depends on the quality of the teacher.	6 6
Can't learn how to learn Success is unrelated to hard work Ability to learn is innate	**Innate ability** Self-help books are not much help. The really smart students don't have to work hard to do well in school. An expert is someone who has a special gift in some area.	5 4 4
Learning is quick Learn first time	**Quick learning** Successful students learn things quickly. Almost all the information you can learn from a textbook you will get during the	5 3

Concentrated effort is a waste of time	first reading. If a person tries too hard to understand a problem, they will most likely just end up being confused.	2

At least two subsets of items were devised to assess each dimension. For example, there are at least two ways in which learners can oversimplify information. They could focus on one aspect of the information (seek single answers), or they could compartmentalise pieces of information (avoid integration).

Both exploratory and confirmatory factor analyses, using the subsets of items as input variables, have produced reasonably consistent four-factor score structures, rather than the five-factor structure predicted. Tables 2.9, 2.10 and 2.11 are the factor score structures resulting from three studies using the Schommer questionnaire. Only factor scores greater than 0.29 are shown. The order of the subset dimensions has been altered in the second and third tables to match that of the first. This makes it easier to see at a glance the commonalities and differences in factor structures. These support the concept of the existence of different dimensions to students' beliefs, however, the subsets of items have not always loaded on the factors originally hypothesised. The four factors identified by Schommer (and based on the factor structure in Table 2.9) are:

Factor 1: "Ability to learn is innate" (Innate Ability)
Factor 2: "Knowledge is discrete and unambiguous" (Simple Knowledge)
Factor 3: "Learning is quick or not at all" (Quick Learning)
Factor 4: "Knowledge is certain" (Certain Knowledge)

The dimension that did not emerge from the factor analyses was Omniscient Authority – students' beliefs in the existence and role of a higher knowledge authority. Item-subsets that did not load as predicted were 'learn first time' and 'avoid ambiguity'. Two item-subsets in the first investigation, 'depend on authority' and 'concentrated effort is a waste of time' did not load strongly on any of the factors. There are minor differences between all four-factor structures. Although there has never been a single, unequivocal structure, the majority of different subsets of questions have consistently loaded onto single factors –

enough to encourage others to continue to use the questionnaire in further research.

Table 2.9. Schommer's (1990) four orthogonal factors (≥0.3) – college level students.

Subset dimension	Factor 1	Factor 2	Factor 3	Factor 4
Learn first time	.62			
Can't learn how to learn	.56			
Success is unrelated to hard work	.55			
Ability to learn is innate	.34			
Avoid ambiguity		.68		
Seek single answers		.56		
Avoid integration		.54		
Don't criticize authority		.33	.30	
Learning is quick	.34		.72	
Knowledge is certain				.53
Depend on authority				
Conc. effort is a waste of time				

Table 2.10. Four orthogonal factors (≥0.3) from Schommer and Dunnell, (1997) – 'gifted' high school students.

Subset dimension	Factor 1	Factor 2	Factor 3	Factor 4
Learn first time	.45			
Can't learn how to learn	.64			
Success is unrelated to hard work	.51			
Ability to learn is innate			.49	
Avoid ambiguity		.55		
Seek single answers		.39		
Avoid integration		.41		
Don't criticize authority	.40			
Learning is quick	.45		.51	
Knowledge is certain				.54
Depend on authority				
Conc. effort is a waste of time			.32	

Table 2.11. Four orthogonal factors (≥0.3) from Schommer (1998) – adult population.

Subset dimension	Factor 1	Factor 2	Factor 3	Factor 4
Learn first time		.46		
Can't learn how to learn		.85		
Success is unrelated to hard work		.38		
Ability to learn is innate	.33			
Avoid ambiguity	.58			
Seek single answers	.60			
Avoid integration	.52			
Don't criticize authority			.34	

Learning is quick	.73	
Knowledge is certain		.62
Depend on authority		
Conc. effort is a waste of time		

Factor scores resulting from the epistemological questionnaire have been found, in a number of studies, to predict numerous aspects of learning, some of which are:

1. The more students believe in Quick Learning, the more poorly they comprehend and monitor their comprehension of social science and physical science texts (Schommer, 1990).
2. The more students believe in Simple Knowledge, the more poorly they comprehend and monitor their comprehension of complex text such as mathematics (Schommer et al., 1992).
3. All four epistemological beliefs predict high school students' grade point average (Schommer, 1993).
4. The older people are, the less likely they are to believe in Fixed Ability, and the more education people experienced, the less likely they were to believe in Certain Knowledge and Simple Knowledge (Schommer, 1998).

5. The less people believe in certain knowledge the more they enjoy engaging in cognitively challenging tasks, and the more that they accurately reflect the inconclusive, tentative nature of the mixed evidence they read (Kardash & Scholes, 1996).

6. Girls are less likely than boys to believe in Quick Learning and Fixed (innate) Ability (Schommer et al., 1997).
7. The less students believe in Simple Knowledge, the more meaningful study strategies they reported using and subsequently, the better they performed on a mastery test. She thus posits that the effect of a belief in Simple Knowledge on learning outcomes is indirect in the sense that students' choice of study strategy may depend more directly on their epistemological beliefs (Schommer, 1993).

Critique of the questionnaire

Schommer (1999 – personal communication) continues to regard her instrument as "experimental" and hence it will be subject to review and perhaps change in the light of further research. The psychometric soundness rests on the replication of factor structures derived in a number of studies, as well as other measures of reliability and validity. Schommer et al (1997) report that inter-item reliabilities for items comprising each factor range from 0.63 to 0.85, and an eight-week test-retest reliability of 0.70. Validity is reflected in that responses to the questionnaire have been found to predict comprehension, metacomprehension, interpretation of information, and integration of information consistent with the theory.

Schommer has collected sufficient data over the past 10 years to be able to suggest a table of factor score weights for three different populations, high school students, college/university students and adults. The caveat over their use is that this data has generally been collected from white, lower-middle class American people and therefore, any extrapolation to a different population requires caution.

Hofer and Pintrich (1997) provide a most useful critique by comparing Schommer's theoretical model and measurement technique against other research-based models. Some criticisms of the theoretical assumptions and methodology offered by Hofer and Pintrich are:

- It is a self-report instrument, which does not allow respondents to make or offer their own meaning.
- It taps only a limited aspect of epistemological beliefs.
- It relies on very broadly stated items, some of which might not be most representative of the domain.
- The internal factor structure of the actual 63 items has not been empirically demonstrated – factor analysis has only been carried out on the 12 subsets of items. (Several exceptions to this will be discussed below.)

Its advantages for education-based studies lie in:

- A new conceptualisation of epistemological beliefs that can foster new ways of approaching problems,

- The efficiency of epistemological belief measurement,
- The output of statistical data suitable for further or related investigation,
- Its applicability to a wide range of students and adults, and
- Its overt links to the educational process.

A review of other studies that have used this questionnaire highlights some of the problems associated with its use. Not all have identified four factors, and some have used a modified form of the questionnaire. Schommer et al, (1992) working with university students, initially identified three factors with eigenvalues greater than 1.0. Quick Learning and Innate Ability merged into a single dimension and the item subsets for Omniscient Authority loaded heavily on the Certain Knowledge factor. However, a four-factor solution emerged with the fourth factor with an eigenvalue of 0.95. This was accepted because of its substantial fit with previous solutions.

Qian and Alvermann (1995) deleted the 10 items relating to Omniscient Authority on the basis that this factor was not identified as a meaningful dimension in previous studies. Initially, they used the 53-item questionnaire with high school students, and attempted exploratory factor analysis with all items rather than item subsets. They then deleted 21 items with factor loadings less than 0.3 reducing the test to 32 items. Factor analysis of these 32 items produced a three-factor solution, which was selected because of its stronger statistical evidence and good fit with the existing theoretical rationale. Simple Knowledge and Certain Knowledge thus merged into a single dimension – Simple-Certain Knowledge.

2.5.14 Choice of questionnaires

Having decided to use a quantitative measure of epistemological beliefs, the issue was whether this should be physics-specific beliefs or more general epistemological beliefs, a choice between using the MPEX or Schommer's questionnaire. The two are compared in Table 2.12.

There is some commonality in the beliefs being measured by both questionnaires. Omniscient Authority (QEB) is similar to the Independence cluster (MPEX) i.e. the naïve or unfavourable belief that teachers, scientists and textbooks have knowledge and that it is transferred to students during learning. Simple Knowledge (QEB) is similar to the Coherence cluster (MPEX) i.e. the naïve or unfavourable belief that knowledge consists of discrete, isolated facts with little integration or coherence. Quick Learning (QEB) is similar to the Effort cluster (MPEX) although the descriptors are not identical. Quick Learning implies that students believe that if something can be learnt, it will be learned or understood in a short time, or not at all. This implies that students believe that putting in effort to learn something difficult will be a waste of time. This lack of effort when the work is hard is the same sentiment expressed in the Effort cluster. The Concepts, Reality Link and Math Link clusters are more definitely related to how students perceive physics and learning physics.

Table 2.12. Comparison between Schommer's Questionnaire on Epistemological Beliefs (QEB) and Maryland Physics Expectations survey (MPEX).

QEB	**MPEX**
Epistemological beliefs: beliefs about the nature and source of knowledge and the process of learning.	Expectations: beliefs about what they will learn and what they will be expected to do. Cognitive expectations: about their understanding of the process of learning physics and structure of physics knowledge.
Not intended for individual assessment. Details of numerous factor analyses available.	Not for individual assessment. Intended to evaluate the impact of one or more semesters of instruction on an entire class. No factor analysis data reported.
Produces data suitable for statistical comparison with other quantitative measures.	Produces ratio of favourable/unfavourable assessments. No robust statistical outcome.
Not subject-specific	Physics-specific
63 items with 5-point Likert scale An adapted version with 43 items has also been used.	34 items with 5-point Likert scale
Both university/college and high school versions available.	University/college version - meant to be used at the beginning and end of a course.
Tests 5 dimensions of which first 4 have been repeatedly found to be independent (using factor analysis): 1. innate ability 2. simple knowledge 3. quick learning 4. certain knowledge 5. omniscient authority First 4 factors accounted for 55% of	Tests 6 dimensions ('clusters'): 1. independence 2. coherence 3. concepts 4. reality link 5. math link 6. effort The first 3 from Hammer's study of epistemology of physics students.

variance and reported to be 'virtually independent dimensions'.	These dimensions are not claimed to be independent of one another.
Each epistemological dimension assessed by two or more sub-sets of questions.	Each dimension is assessed by one subset of questions.
Scale: from naive to sophisticated. From absolutist to constructivist.	Scale: from unfavourable to favourable.

Both of these are experimental instruments and the selection of either one brings with it some limitations and possible criticism. Despite the physics content appeal of the MPEX, I ultimately decided to use Schommer's questionnaire. Many of the MPEX questions were representative of a different culture of education – the American context is different from Australian classrooms. The MPEX questions were more difficult to modify to eliminate potential cultural and educational differences, than those in the Schommer questionnaire. The

MPEX was defined in terms of 'expectations' rather than beliefs. While beliefs and expectations are not the same, beliefs lead to an expectation of continuity (Bem, 1970) and hence beliefs underpin expectations. However, the less overtly epistemological nature of the MPEX would make it more difficult to link this research to existing epistemological belief research. Links to the MPEX can still be made, however, because there appears to be an overlap of several dimensions.

At the time of making this decision, I did not have the van Aalst and Keys' (2000) paper in which they found a relationship between the subject context and results on the MPEX that they attributed to different motivational factors. This may have had a significant effect in this study when comparing Engineering undergraduates with Physics/Geophysics undergraduates.

2.5.15 Review of Section 2.5

These studies clearly point to a link between epistemological beliefs and effective learning although the nature and mediators of that link can only be hypothesised. No model of learning exists to tie all aspects together into a coherent theory.

It is probable that first year university students, although likely to be more sophisticated in beliefs than they were in high school, still harbour many beliefs about knowledge that are different from their instructors. It is reasonable to assume that students who have selected to pursue physics at a tertiary level achieved a degree of success in that discipline at school. If so, there is likely to be a degree of concurrence between these students' beliefs and the way in which knowledge and knowing were portrayed to them in high school.

There is some suggestion also that students of physics, and the harder, more quantitative subjects such as mathematics, may be more naïve than their contemporaries who have chosen a more humanities-oriented field in which diversity of opinion, lower emphasis on seeking 'right' answers and more subjective types of assessment are accepted. If students with naïve beliefs in, for example, the certainty of knowledge and deference to Authority, achieve success, there will be little reason for disequilibrium – a precursor to change. Hence, we might expect physics/engineering students to enter university with more naïve epistemological beliefs than their arts or social science contemporaries.

From the point of view of this research, I must assume that physics students entering the Studio course will find the learning environment different from their high school experiences. As a result they are likely to experience some *disequilibrium* between their expectations and their actual experiences. This should result in some change in beliefs over the year. Engineering students entering the Lecture physics course are likely to find the learning environment somewhat similar to their high school experiences and more in line with their expectations. It is likely, therefore, that they will retain their more naïve epistemological beliefs because of the decreased likelihood of disequilibrium.

There appear to be residual problems in measuring students' epistemological beliefs although evidence for the existence of a number of dimensions to beliefs is strong. There is also evidence for some form of domain dependence, which implies that students do hold different beliefs depending on the context. Students' belief systems do not appear to be coherent or exercised consistently. It is therefore likely that a single instrument will not fully capture the essence of beliefs, and that both qualitative and quantitative methods may be required.

If we have a better understanding of the existence, nature and malleability of naïve epistemological beliefs, and how they impact (positively or negatively) on cognitive outcomes or negative attitudes, this is an important step towards developing and implementing meaningful and potentially productive or appropriate epistemological instruction in university classrooms. If students in the Studio course have beliefs that are unexpected, the genesis and effect of such beliefs need investigating to ascertain usefulness or disadvantage.

2.6 Beliefs

> *Only a very unparochial and intellectual fish is aware that his environment is wet.*
>
> (Bem, 1970, p. 5)

Literature drawn from psychology on the nature, strength and malleability of beliefs and attitudes has been included in this review of research literature because it affects this study in a number of ways. Firstly, most literature on epistemological beliefs does not address the nature of a belief, instead focussing on the *knowledge* aspect. Secondly, the terms *belief* and *attitude* are used in relation to 'self-efficacy beliefs' and 'attitudes to the learning environment' and there should be a common understanding of the terms. Thirdly, students' alternative conceptions in physics have many of the characteristics of *beliefs* rather than *knowledge*.

2.6.1 Nature of beliefs and attitudes

For this section on the nature of beliefs and attitudes, I draw heavily on Rokeach (1968) and Bem (1970). Rokeach has incorporated or critiqued the work of many predecessors and contemporaries in defining belief, belief systems, attitudes, and belief and attitude change. Although he precedes more recent proponents of radical or social constructivism, Rokeach adopts a person-centred position that is more consonant with a constructivist view of the individual than the positivist epistemology prevalent at the time. Bem also emphasises the importance of individuals' sensory experiences in belief formation and maintenance. More recent works that I have consulted (Pratkanis, Breckler & Greenwald, 1989; Roseman, 1994; Schank, 1994) place little importance on constructing common meanings for terms such as belief, preferring to discuss them within the context of specific behaviours or situations. Hence, it has been difficult finding relevant papers on beliefs and attitudes in relation to beliefs about knowledge.

Belief

Rokeach emphasises that beliefs and attitudes can only be an external observer's inference of such. We cannot directly know the beliefs of others:

> *Beliefs are inferences made by an observer about underlying states of expectancy … like motives, genes and neutrons, [they] cannot be directly observed but must be inferred as best one can, with whatever psychological devices are available, from all the things that a believer says or does* (p 2).

Attitude

> *An attitude is a relatively enduring organization of beliefs around an object or situation, predisposing one to respond in some preferential manner* (p. 112)

The key words in this definition are *enduring* which suggests a time dimension or stability, *organization of beliefs*, which suggest a focussed, interrelated and irreducible grouping of beliefs, and finally *respond*, which indicates that believers will act in ways consonant with their attitudes. This definition, although not universally agreed, provides a way of interpreting epistemological beliefs and students' resultant learning behaviours. It also accommodates the concept of belief change.

Each belief within an attitude is conceived to have three components, cognitive, affective and behavioural. The cognitive component refers to a person's knowledge and his or her judgement of its degree of certitude. The affective component refers to the emotional response if the belief is challenged. The behavioural component refers to some preferential action resulting from the belief, should the situation arise. All attitudes incorporate beliefs but not all beliefs are necessarily part of attitudes. Breckler and Wiggins (1989) also conceive of attitudes being a system of beliefs but the difference is that there is an affective value judgement or like/dislike component to attitudes. Pajares (1992) also uses a three-part belief structure (cognitive, behavioural and affective components) to distinguish belief from knowledge – suggesting that beliefs are more likely than knowledge to be defended when questioned.

2.6.2 Belief categories

Rokeach (1968) makes three assumptions about the nature of beliefs:

1. Not all beliefs are equally important to the individual;

2. The more ‘central’ the belief, the more it will resist change; and
3. The more central the belief changed, the more widespread the repercussions in the rest of the belief system.

The ‘centrality’ of a belief is related to the number of other beliefs or concepts dependent on it i.e. the ‘connectedness’ of that belief. The most central of all beliefs are existential ones; those concerned most intimately with the believer's own existence and identity. Less central are ‘shared’ beliefs about the believer’s existence and identity – related to family or close group membership. Less central are those learned not by direct encounter but indirectly through authority figures (people or organizations) and other reference persons. The least central are those that concern matters of taste and preference. All beliefs can be ordered on a central-to-peripheral continuum.

These classes of beliefs are based on the degree to which the believer has had direct encounter with the object of the belief (primitiveness) and the degree of social consensus that the believer knows supports that belief. See Table 2.13.

The centrality of beliefs does not equate to ‘intensity’ or ‘verifiability’ of beliefs. Intensity of belief (how strongly they are held) can range from low to high within any of the classes. High intensity beliefs are strongly held and defended. Verifiability refers to whether or not the believer thinks his or her beliefs can be verified by someone else, rather than whether or not their beliefs are ‘true’. Type B beliefs, which are deeply personal, are unverifiable because the believer thinks that only he or she could possibly know about that belief. Beliefs can also be ordered on a continuum ranging from belief to disbelief.

Bem suggests that all beliefs are part of frameworks with horizontal and vertical structure, with the most primitive beliefs forming the lowest or Zero-Order layer. Higher orders are formed through syllogistic reasoning but always resting on primitive beliefs. Bem’s view of ‘primitiveness’ is similar to Rokeach’s in that it reflects the believer’s direct experience:

> *Every belief ... rests ultimately upon a basic belief in the credibility of one’s own sensory experience or upon a basic belief in the credibility of some external authority* (p. 5).

Table 2.13. Five types of belief (Rokeach, 1968)

Belief Type	Description of belief	Belief characteristics
A	Primitive beliefs, 100% consensus	• Beliefs learned by direct encounter with the object of belief (perceived reality and social reality) and concerning matters to do with the very existence and identity of the self. • Reinforced by unanimous social consensus. • Have an axiomatic, taken-for-granted character embodying object and person constancy. • Incontrovertible (unquestionable). • An example might be "I believe my name is Susan."
B	Primitive beliefs, zero consensus	• Entirely personal, not shared, hence impervious to persuasion or argument by others. • Learned by direct encounter with object of belief. • Held on pure faith – like phobias, delusions etc. • Incontrovertible. • Examples might be "I believe I am a stupid person" or "I believe I am not lazy."
C	Authority beliefs	• Non-primitive beliefs about authority figures, doctrines, social mores and customs, based on trust or credibility. • Less important than Type A or B beliefs but still resistant to change. • Develop out of Type A beliefs – once totally 'true' and shared, but now subject to some debate or differences of opinion. • Incontrovertible (to the believer). • Examples might be "I believe that my parents are good people" or "I believe what is written in the bible."
D	Derived beliefs	• Derived from 'credible' others. • Ideological beliefs learned through experience or identification with a trusted authority figure and their beliefs. • Related to 'matters of fact'. • Controvertible. • Examples relate to 'facts' learned in school, or through 'credible' television programmes. For example " I believe Newton's Laws describe motion" or "I believe genetically modified foods are harmful."
E	Inconsequential beliefs	• More or less arbitrary 'matters of taste'. • Originate in direct experience with object of belief. • Can be intensely held and defended. • Maintenance does not require social consensus. • Controvertible. • An example might be "I believe that holidays in summer are better than holidays in winter."

According to Bem, Zero-Order beliefs are so taken-for-granted that we are apt not to notice that we hold them, that is until they are called to our attention or brought into question by some circumstance in which they appear to be violated. Much of this is associated with the expectation of continuity, stability and orderliness of our perceptions. However, faith in the validity of one's sensory experience is the most primitive belief of all and no justification (or further justification) of such beliefs is needed. The opening quote in this section on beliefs is how Bem illustrates the nature of a primitive belief for the believer.

Similarly, no justification, beyond a brief citation, is needed for First-Order beliefs, which are directly dependent on Zero-Order beliefs through syllogistic reasoning. The believer, however, is not aware of the inferential process by which they derive First-Order beliefs. Stereotypes or generalisations, which are cognitive processes for making sense of the world, are also First-Order beliefs requiring no justification.

Bem recognises the centrality of beliefs – their importance to other beliefs – as the degree to which they are syllogistic to other beliefs in the belief structure. He also distinguishes between *core* beliefs (linked to many others) and *peripheral* beliefs (linked to few others). Hence, Bem does not subscribe to a random collection of beliefs but rather that individuals maintain a coherent system of beliefs that are internally consistent. Even when some beliefs are changed, if they are part of a structure, the rest of the belief structure does not necessarily collapse. It is this type of coherent structure that Hofer and Pintrich (1997) appear to envision for personal theories of knowledge and knowing. Alternative physics or science conceptions may also form a similar belief system.

2.6.3 Belief versus knowledge

Is belief the same as knowledge? Does it have the same status for an individual? This depends on whether one takes a philosophical or psychological view of *epistemology*. In philosophy, epistemology is a synonym for the theory of knowledge and its justifiable basis, and includes logical categories of knowledge. Philosophy is thus concerned with the nature of 'truth'. Zagzebski (1999) adopts the view that knowledge is a form of believing a *true* proposition. Beliefs are considered to be unwarranted knowledge claims and are thus weaker than knowledge. On the other hand, psychology is concerned with the nature, structure and development of knowledge, especially individual knowledge. In psychology, epistemology refers to theories of knowledge growth and development, structures of knowledge and general theories of conditions of learning. Hence, in psychology, a person's beliefs are regarded as stronger than their knowledge. A constructivist position might be that, for the individual, there is no difference between belief and knowledge.

Kardash and Scholes (1996), in investigating epistemological beliefs, distinguish between belief and knowledge in that "a belief can be false" and "a belief may be based on insufficient evidence". Such a claim seems unsupported from a constructivist position. A value judgement about the veracity of a belief, made from an external perspective, does not distinguish between belief and knowledge from the believer's point of view. This description of the nature of a belief is closer to what Rokeach classifies as a faith or a delusion (a view strongly held even in the face of considerable opposition), rather than an external view of the holders' perception of reality. From a constructivist position, the notion of a 'false' belief is probably untenable. A belief, *for the believer,* has a taken-for-granted quality or truth, regardless of the expressed views or evidence of others. A belief can have meaning only to the believer, even though the believer may consider it to be a shared, consensual belief. That a 'wrong' belief can be based on 'insufficient evidence' also assumes a status of truth that is inconsistent with a radical constructivist position.

2.6.4 Measuring or assessing beliefs and attitudes

Determining the nature of a person's beliefs is a difficult task. If a person says "I believe that … …", what credence can we place on the notion that this is a faithful representation of that person's belief? This is but an articulated belief, or representation of it – whereas many implicit beliefs are simply unarticulated – especially where a person has never needed to consider the veracity of such a belief.

Hammer (1994) describes difficulty in getting physics students to articulate beliefs that they have never actually thought about, or don't normally think about. He eventually interpreted many of his students' beliefs about physics and physics knowledge through the metaphors that they used, either intentionally or implicitly. Hence, it would appear likely that self-reported beliefs might form only a fraction of a person's actual belief system. For us to know more about a person's belief system, we need to infer that which is not faithfully articulated.

2.6.5 Belief change

Beliefs form initially in children as primitive beliefs, through contact with family members, social sphere and the physical world. They undergo modification as belief objects or belief situations change, or as the child perceives differences in them, or as the child is introduced to more sources of belief, such as new authority figures or organizations. Beliefs can be changed if a source of veracity exists, and if that source is persuasive.

Reasoning as belief revision

Chapman (1993) contrasts two forms of belief revision, *internalist* and *externalist*. He cites Harmon (1986) who proposes the following internalist principles of belief revision:

1. *Positive undermining*: One should reject a belief when one has some positive reason to do so.
2. *Conservatism*: One should retain a belief in the absence of any specific reason to reject it.
3. *Clutter Avoidance*: One should not clutter one's mind with trivialities.

> *Taken together, these principles imply that reasoners should attempt to maximise the coherence of their beliefs with a minimum of changes and that they should do so without keeping track of the reasons involved in past revisions. Keeping track would lead to an accumulation of potentially trivial information which would be dysfunctional for learners with finite processing resources.*

(Chapman, 1993, p. 108).

Behaviour can change attitudes and beliefs. Bem (1970) observed that students changed their beliefs when encouraged to engage in an activity that supported a different belief. He cites Festinger's Theory of Cognitive Dissonance to explain such observations. This theory suggests that:

> *If a person is induced to engage in behaviour that is inconsistent with his beliefs or attitudes, he will experience the discomfort of cognitive dissonance, which will motivate him to seek a resolution of that inconsistency… …One way he can do this is to*

> *convince himself that he actually believes in what he has done, that he actually holds the beliefs or attitudes implied by the behaviour* (p. 55).

Thus, change in epistemological beliefs may follow involvement in activities that support different beliefs.

2.6.6 Links to epistemological belief research

Rokeach posits that a person's social behaviour will always be mediated by at least two types of attitude, one activated by the *object* and the other activated by the *situation*. It follows that behaviour is a function of the interaction between two attitudes – attitude-toward-object and attitude-toward-situation. This conception of an attitude suggests that a person might hold certain beliefs about the nature of knowledge, for example, but their response will depend on the nature of the task they must accomplish in representing their knowledge. This view provides some support for the notion of the domain dependence of epistemological beliefs, such as in learning physics. For example, students' beliefs about the nature of knowledge and the process of knowing (attitude-toward-object) are activated with their beliefs about the process of learning physics (attitude-toward-situation). It is therefore possible that investigation into epistemological beliefs within different domains involves tapping into students' different attitudes rather than underlying beliefs.

Hofer & Pintrich (1997) suggest that core epistemological beliefs be distinguished from about beliefs about learning, intelligence and teaching, which they term peripheral beliefs. Rokeach's two-component conception of an attitude provides a supporting perspective whereby the epistemological beliefs might represent one attitude-toward-object (knowledge, knowing) and beliefs about learning and teaching might represent different attitudes-toward-objects. *Core* beliefs about knowledge and knowing may be different from *peripheral* beliefs about learning, intelligence and teaching, however, it is the notion that one is *core* and the other, *peripheral*, that is possibly open to argument. Core and peripheral in relation to connectedness of beliefs is not the same as core and peripheral as Hofer and Pintrich use it.

Schommer has proposed that there are five belief dimensions, of which she (and others) has identified four. The four identified dimensions are belief in the simplicity and certainty of knowledge, and belief in quick learning and innate ability. It is plausible that that the first two form part of one attitude-towards-object and the second two form part of a second attitude-towards-object. It is possibly the same belief system but two ‘objects’.

Hofer and Pintrich also suggest that epistemological beliefs be regarded as personal theories. Theories have some coherence among constitutive ideas and components, make some ontological distinctions between different entities and processes in the domain, and provide a causal-explanatory framework for the phenomena in the domain (Wellman, 1990). In a similar vein, Rokeach compares an attitude with a scientific theory:

> *An attitude can be likened to a miniature theory in science, having similar functions and similar virtues and vices. An attitude, like a theory, is a frame of reference, saves time because it provides us with a basis for induction and deduction, organises knowledge, has implications for the real world and changes in the face of new evidence. A theory, like an attitude is a pre-judgement; it may be selective and biased, it may support the status quo, it may arouse affect when challenged and it may resist change in the face of new evidence. An attitude in short may act in varying degrees like a good theory or a bad theory, and depending on what kind of theory an attitude acts like, it may serve one function better than another* (p. 131).

Classifying epistemological beliefs

Epistemological beliefs may be seen as Type A or Type B beliefs (both primitive, existential and highly central) if one takes the view that trust in one’s own senses as a way of knowing, of perceiving and understanding the world, constitute such central beliefs. See Table 2.13. Certainly, challenges to an individual’s Type A or B beliefs are, in effect, challenges to the credibility of his or her senses, and will be met with resistance. On the other hand, it seems likely that by the age of 17 – 18 when students are entering university, their primitive beliefs about knowledge and knowing are likely to have been moderated or reformed by educational experiences and direct and indirect contact with a range of authority figures and organisations other than parents and immediate family.

The most plausible classification is that they are Type C and Type D beliefs, related to trusted authority figures (Type C) and to beliefs derived by accepting the beliefs of trusted others (Type D). If, however, some primitive beliefs have never been challenged or perceived to have been challenged, such as belief in innate ability (the ability to learn is determined at birth), then they may still have a Type A or B element associated with them. Hence, it seems that epistemological beliefs cannot easily be classified because they form part of different belief structures in different individuals.

2.6.7 Review of Section 2.6

Definitions of belief and attitude provided by Rokeach, Bem and others provide a useful framework for thinking about epistemological beliefs, beliefs that are related or linked with them and epistemological belief change. Beliefs are taken-for-granted truths linked to expectations about the world. They form part of a coherent belief system. For the individual, beliefs are indistinguishable from knowledge, although they have affective and behavioural components that predispose the individual to act in certain ways. Beliefs that are central, primitive and existential are hardest to change, and if changed, have greater repercussion on the rest of the belief system as well as emotional disturbance for the individual. They have a structure or framework that may exist even when the original or underlying belief rationale is obscure or changed. Attitudes are groups of beliefs.

2.7 Review of Chapter 2

In this chapter, I have reviewed the literature related to the five main areas that underpin this study: cognition, learning physics, learning environments, epistemological beliefs and the nature of human beliefs. In the next chapter, I will outline details of the planned research methodology and how the research programme was conducted.

2.8 References for Chapter 2

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CHAPTER 3: METHODOLOGY

Selecting the method most appropriate for a particular disciplined inquiry is one of the most important, and difficult, responsibilities of a researcher.

The best research programs will reflect intelligent deployment of a diversity of research methods applied to their appropriate research questions.

(Shulman, 1981, pp. 11-12)

3.1 Introduction

This chapter is divided into two sections. In Section 3.2, I will discuss theoretical issues and decisions related to the research methodology adopted, before outlining the research questions. Following this I will describe the research program, data sources and procedures, and how data analysis was undertaken. Finally, I will present proposed methods for assuring quality of research and research outcomes. In Section 3.3, I will outline the technique, processes and quality criteria related to multidimensional scaling. This technique will be used to investigate patterns of difference and change in the learning environments. It uses data that are described in Section 3.2.

3.2 Research methodology

3.2.1 The paradigm debate

When I began this study, I faced the very difficult task of deciding *how* to best research the problem. I became embroiled in the seemingly inevitable 'paradigms' debate. Paradigm is commonly taken to mean 'world view'. It was popularised but used somewhat ambiguously by Kuhn in his seminal work "The Structure of Scientific Revolutions" (Kuhn, 1970), to differentiate between two historical extreme epistemological and ontological views of 'scientific' knowledge. He describes how the Galiliean causal and mechanistic paradigm supplanted the Aristotelian teleological reasoning process. More recently, a paradigm has come to mean that which determines the criteria according to which one selects and defines problems for study (Husén, 1988).

The extrapolation of paradigms from their epistemological foundations to paradigms that guide science education research methodologies has resulted in a degree of uncertainty about their relevance or usefulness (Keeves, 1998). Walker and Evers (1988) describe three alternate views on paradigms, particularly with respect to education research: (1) First, there *are* epistemologically different paradigms which are incommensurable in that neither educational research nor any other form of inquiry can provide a rational method for judging between them. They are mutually incompatible, competitive ways of researching the same territory. Guba and Lincoln (1985) argue strongly for this point of view. (2) The second view is that there *are* epistemologically distinct paradigms, one scientific and the other humanistic in origin, and although incommensurable, they are complementary and equally appropriate ways of approaching different or even the same research problem. This view is strongly supported by researchers such as Shulman (1981) and Patton (1990). (3) The third view is that different paradigms are epistemologically untenable and *do not exist*. This view asserts a fundamental epistemological unity of education research, derived from the practical problems addressed. Walker and Evers' term for this is "materialist pragmatist" epistemology. Its foundations are the post-positivist 'naturalist' epistemological theory of Quine (1998). Keeves (1998) also supports the unity view but by suggesting that the two paradigms are supplementary.

Physics is normally associated with a neo-positivist, or logical empiricist 'scientific' view of reality and knowledge development. Research that is modelled on the natural sciences, such as physics, normally seeks to establish causal relationships or to explain phenomena. Since this study is about analysing the outcomes of teaching methods aligned with an epistemology associated with a constructivist paradigm, good sense might dictate that the study design should be consonant with a humanistic philosophy. Research modelled on the humanities is holistic, normally seeking to understand and interpret. And yet, if I adopted only an interpretive or phenomenological methodology, I would risk missing information that might be of critical importance in understanding the whole situation.

3.2.2 A pragmatic approach

While paradigm unity is an attractive proposition for this study, there is no practical difference between the methods of inquiry under complementary paradigms or supplementary paradigms. The 'rules of evidence' are determined by the problem being researched, the research strategy chosen and the type of data collected. Both quantitative and qualitative data can be collected within either research tradition (Keeves, 1998; Patton, 1990).

> *The advantage of a quantitative approach is that it's possible to measure the reactions of a great many people to a limited set of questions, thus facilitating comparison and statistical aggregation of data. This gives a broad, generalisable set of findings presented succinctly and parsimoniously. By contrast, qualitative methods typically produce a wealth of detailed information about a much smaller number of people and cases. This increases understanding of the cases and situations but reduced generalisability.*
>
> (Patton, 1990, p. 14)

I have therefore taken the pragmatic view that the nature of the research aims and questions should dictate the various research strategies employed. Criteria for quality of research method and outcomes will therefore be based on each research strategy used and type of data collected, as outlined by Keeves (1998). The study has elements relevant to evaluation research, longitudinal research, and survey research methods. It adopts an experimental design in which both qualitative and quantitative data are collected and analysed as shown in RED in Figure 3.1.

Epistemological foundations of research

The principles of constructivism will guide the research program insofar as knowledge is believed to be constructed by the individual (which includes the researcher) but socially mediated. It is important to note that epistemologists in general agree that inquiry structures our knowledge of the objects of our inquiry. This 'constructivist' view is not a feature peculiar to qualitative inquiry and hence is not incommensurate with any research paradigm (Walker & Evers, 1988).

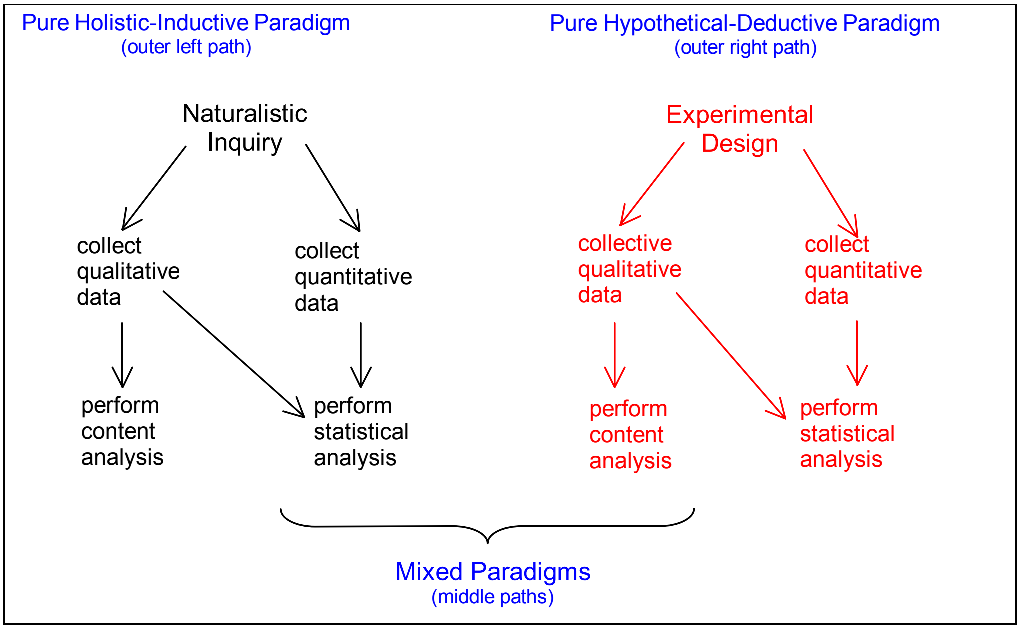

Figure 3.1. Measurement, Design, and Analysis: Pure and Mixed Combinations. Adapted from Patton, 1990, p. 195.

3.2.3 Some issues related to education research

There are two main research issues that concern this study. The first is the replicability and applicability of education research and the other is the subjectivity/objectivity debate, especially if the researcher is an integral part of the object of study.

Replicability and applicability

Education research, in general, is difficult to replicate and has been shown to have limited applicability. It has already been pointed out in Chapter 1 that student learning in higher education is on the boundary of two disciplines – education and cognitive psychology – and that problems of combining psychology and education result from the different goals and pursuits of the two fields of research (Richardson, 1987). One might also argue that psychology uses the methods of scientific research, which assumes a predictable and constant future based on past observations. According to White (1998), applying the rules of scientific research to human subjects and education has been largely unsuccessful in terms of generalisability. He argues that:

> *Contexts are variable and ephemeral, and human beings so individual and wilful, that few relations between variables hold widely enough or stand for long enough to be useful* (p. 56).

The problems appear to stem from the researcher's inability to control confounding variables – a key feature of the experimental tradition. White, however, tempers this pessimistic view with an account of the highly replicable studies on students' alternative science conceptions.

Reflexivity in research

Even in scientific research, pure objectivity is not possible despite the theoretical ideals espoused initially by Descartes (i.e. that genuine knowledge had to be free of external influences and determination) and supported since by proponents of scientific endeavour independent of human influence. Feminist philosophers, in particular Longino (1999) and Sartori (1994), have questioned the ability of, or in fact need for, scientific researchers to be objective. They assert that the ideal of a value-neutral science is misconceived and that there is no way of eliminating *a priori* the incorporation of values in hypothesis formation and evaluation. Some degree of subjectivity must be expected.

A solution is for researchers to be reflexive in their endeavours – to recognise and publicly acknowledge their own input in the process. Constructivists recognise that learners, researcher included, construct different understandings of data and how they are interpreted, and which may result in different 'realities' for each. This has important implications for researchers who are also involved in the object of their study. As Steier (1995) points out:

> *Researchers of human systems need to keep in mind their contributions to the phenomenon they analyse – which, in turn, contribute to their constructions of the system being investigated.* (p. 80).

Thompson (1992) suggests that reflexivity in research entails the researcher reflecting on:

1. Their sense of the research domain,
2. How that sense is expressed in their researching actions,

3. The contribution their actions make to the behaviour they wish to study, and
4. How their observations of behaviour influence their sense of the research domain.

Hence, a researcher cannot be totally objective; their responsibility therefore is to reflect on and discuss how their actions influence the study and how the study influences their judgements and conclusions.

3.2.4 Methodological design of study

The most succinct description of the study design is an evaluation of learning in a particular learning environment. Patton (1986; 1990) uses the term *evaluation* quite broadly to include any effort to increase human effectiveness through systematic data-based inquiry. King, Lyons Morris and Taylor Fitz-Gibbon (1987) propose that a summative evaluation, which uses a highly controlled design and valid outcome measures, may constitute a research study. This is appropriate for evaluating students' cognitive outcomes and assessment of their perceptions of their learning environment. Fraser (1998), however, suggests that obtaining students' perspectives or beliefs about their learning environment solely through quantitative means presupposes the existence of given perspectives. Allowing students themselves to reveal their full range of views and understandings of their learning environment requires an interpretive approach. Hence, qualitative data, including interview transcripts, written artefacts and researcher notes have been collected, following evaluation research methods described by Patton (1990) and supported by interpretive, participant observational fieldwork described by Cohen and Manion (1989). Because the data collection phase of this study has taken place over eight months, it has some of the characteristics of a longitudinal study, hence documentation of process and change has been important.

3.2.5 Research overarching questions

1. What are the cognitive outcomes of students learning physics in the first year Studio course?
2. How do these students assess and respond to the social constructivist nature of their learning environment?

3. What is the nature of the interrelationships among students' perceptions of the learning environment, epistemological beliefs and cognitive outcomes?
4. And finally, how can these multiple interrelationships be made explicit or understandable?

3.2.6 Specific research questions

1. What are Studio students' learning outcomes?
   a) Do students in the Studio course out-perform those in the traditional course as measured by common assessment instruments?
   b) Do students in the Studio course out-perform those in the traditional course as measured by concept-testing instruments?
   c) Do students develop skills and confidence in using computers?
2. What roles do Studio students' perceptions of their learning environment play in their physics learning?
   a) What are Studio students' perceptions of their actual and preferred learning environment, and how are they different from those of students in the traditional course?
   b) Are Studio students' perceptions of their learning environment related to their physics learning outcomes?
   c) Do Studio students apply self-reflection skills?
3. What roles do Studio students' epistemological beliefs play in their physics learning?
   a) What are students' initial epistemological beliefs?
   b) Are students' epistemological beliefs related to their physics learning outcomes?
   c) Are students' epistemological beliefs related to their perceptions of the learning environment?
   d) Does participation in the Studio course change students' epistemological beliefs?
   e) What study methods/processes do students favour?
4. Can multidimensional scaling techniques be used to represent and differentiate between the Studio and Traditional learning environments?

Figure 3.2 is a flow chart showing the links between data sources and the relevant Research Questions.

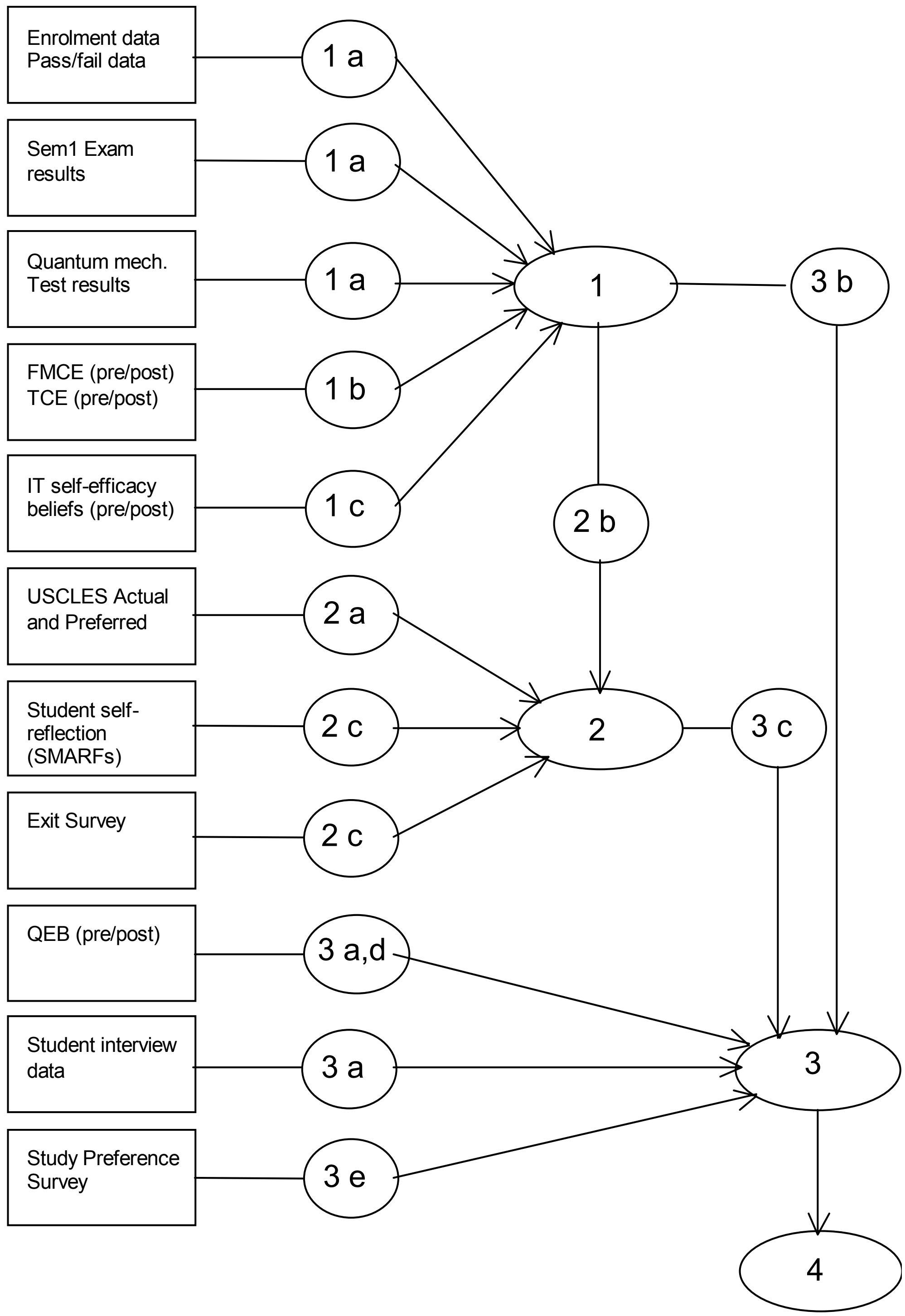

Figure 3.2. *Flowchart showing links between data sources and research questions and sub-questions. See glossary for meaning of acronyms.*

3.2.7 Research design

This research study is in two parts. The first part (Comparative Study) has an Ex-Post Facto Group Comparative design using matched subjects in two different instructional environments. It primarily seeks to investigate differences between the Studio Instruction (SI) group and traditional Instruction (TI) group. It also includes elements of survey research. This part is described in Chapter 4. The second part (Correlational Study) uses the same student groups. It seeks to investigate differences and variation between students within each group, and will be described Chapter 5. Figure 3.3 illustrates such different categories of education research.

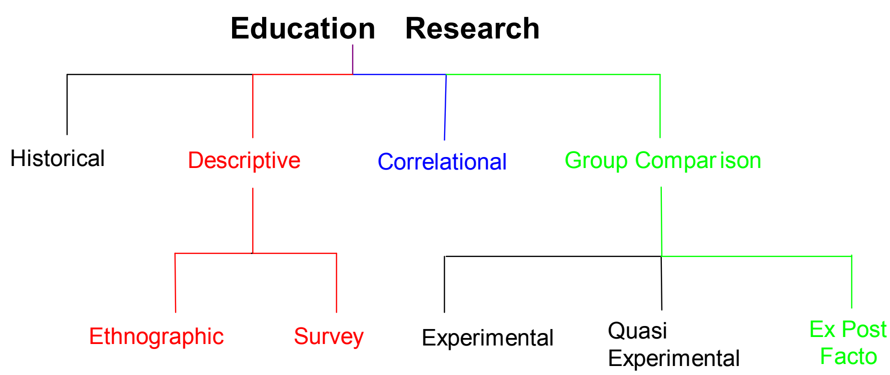

Figure 3.3. Flow chart showing categories of education research - adapted from Crowl, 1989, (Fig. 1.1, p.9).

Figure A.2.1 (Appendix) is a flow chart showing the links between various data sources and the two parts of the study.

Experimental control

It is not possible to measure and evaluate the cognitive outcomes of SI students in absolute terms. That is, one cannot measure in absolute terms, the amount of physics and related skills they learn, and establish whether or not their cognitive outcomes are better or worse than if they had not been involved in a particular learning environment. However, this question inevitably will arise. The only realistic means of measuring learning outcomes is in relation to a comparable group of students undertaking the same course but in a traditionally organised and taught situation. This situation existed for all engineering students, plus a few students in other faculties – fortuitously providing a comparable control group. Without the

Studio, all students taking Particles and Waves 101 and Structure of Matter 102 would be in traditional classes.

Subjects and groups

Data was collected for ALL students in the Studio (SI) and Traditional (TI) classes throughout the year, but the composition of the ‘matched groups’ decided only at the end. This was done primarily to ensure that there would be sufficient data to make statistical comparisons between groups, given that the data collection was planned to extend over eight months (two semesters). There is normally an attrition of students from both Studio and lecture streams in both semesters as well as a daily absentee rate of 10-40%, and these would be a considerable threat to viable numbers if matched groups had been selected at the beginning of the study. In addition, this avoided the bias that might have been introduced had some students been given surveys or questionnaires and others not.

Table 3.1 illustrates the matching criteria and composition of the two groups used for all comparative parts of the study. Some data was not unequivocally reliable or obtainable for all students. For example, the Tertiary Entrance Examination (TEE) physics mark was self-reported and Tertiary Entrance Rank (TER) was not available for students who had completed an overseas or late entry qualification. The TER is an average aggregate of subject scores obtained on external examinations used to qualify a student for university entrance.

3.2.8 Data sources and instruments

The selection and timing of instruments were chosen carefully for the following reasons:

1. The need to control the volume of data to be collected and processed;
2. Considerations related to equality of timing of the assessment instruments (the Studio and Traditional courses do not always keep pace with one another);
3. Concern about over-burdening students with too many additional assessments or surveys;

4. Towards the end of the year, the content of the two subjects diverge, despite having the same subject name; and
5. The need for a broad rather than overly narrow comparative approach.

Table 3.2 outlines all data types and sources.

Table 3.1. Criteria and composition of the comparative groups – SI (studio instruction) and TI (traditional instruction).

Criteria[a]	**SI**	**TI**
TEE physics mark	Mean = 72.6 St dev = 8.1 (N = 40)	Mean = 72.6 St dev = 8.7 (N = 64)
TER	Mean = 91.95 St dev = 5.76 (N = 33)	Mean = 91.13 St dev = 5.32 (N = 58)
Ratio male:female	5.4:1	7.7:1
Ratio English speaking:Non-English speaking background[b]	8.0:1	7.7:1
Ratio Perth metroplitan:country or overseas students	4.0:1	6.0:1
Number of students in each group	45	70

[a] To be eligible for inclusion, students must have remained enrolled for the whole year and have no more than two pieces of data (i.e. test results, surveys) missing.
[b] All included Non-English Speaking Background (NESB) students have spoken English for more than five years.

Measuring cognitive outcomes - 'traditional' knowledge

Customary assessment of physics learning outcomes in the PW101 and SOM102 courses is by test, examination (mostly multiple choice questions) and assignments. Assignments use fairly routine problem solving items but because students may seek help or other forms of assistance, this type of assessment was considered invalid for the purpose of this research. Examination questions are of two types, problem solving and conceptual physics understanding. Both may be combined in the same question.

The instruments used were:

1. Semester 1 Examination administered in June under examination conditions. See Appendix A.1.1.

2. Test 3 (Quantum Mechanics) administered in Term 3 at the end of the Quantum Mechanics unit, under examination conditions. See Appendix A.1.2.

Measuring cognitive outcomes - conceptual knowledge and conceptual change

The customary forms of assessment for first year physics test for problem-solving ability (calculation) and some conceptual knowledge. By their nature, they do not test for deep conceptual knowledge. Thus, conceptual tests were included to test for students' deep-seated beliefs about key physics concepts. The instruments used were:

1. Force and Motion Conceptual Evaluation (FMCE). This was administered in the first week of Term 1 (pretest) and again in the seventh week (posttest). See Appendix A.1.3.
2. Thermal Concept Evaluation (TCE) (Yeo & Zadnik, 2001). This was administered in the first week of Term 3 (pretest) and again in the fifth week (posttest) to SI students only. See Appendices A.1.4 and A.3.1.

The FMCE tests for students' Newtonian physics understanding. A numerical total was obtained following the method recommended by Cummings et al (1999). The four questions on conservation of energy were also included in the total.

The TCE tests for students' beliefs about heat, temperature and thermal energy transfer, and the extent to which they prefer and use a kinetic model explanation for thermodynamic phenomena. Students in the traditional course for SOM102 do not study the Thermodynamics component. The TCE was used with the SI students to see if the type of conceptual understanding gains made in Semester 2 in a different topic replicated those with the FMCE in Semester 1.

The TCE was produced, trialled with almost 500 students and validated through interviews with students as part of this research study because no other suitable instrument was available at the time. Details of this process will not be reproduced here as a paper on the TCE instrument was published in November 2001 in The Physics Teacher. This journal article is included as Appendix A.3.1.

Table 3.2. Data types and data sources for both groups

Data	**Data sources**	
	Studio Instruction group	**Traditional Instruction group**
Physics knowledge and learning (cognitive outcomes)	Semester 1 Exam (EXAM) Quantum Mechanics Test (QM TEST)	Semester 1 Exam (EXAM) Quantum Mechanics Test (QM TEST)
Prior physics and general knowledge	Tertiary Entrance (physics) Examination result (TEE) & Tertiary Entrance Rank (TER)	Tertiary Entrance (physics) Examination result (TEE) & Tertiary Entrance Rank (TER)
Physics conceptual understanding and conceptual change (cognitive outcomes)	Force & Motion Conceptual Evaluation (FMCE) – Pre- and posttest Thermal Concept Evaluation (TCE) – Pre- and posttest	Force & Motion Conceptual Evaluation (FMCE) – Pre- and posttest
Epistemological beliefs	Questionnaire on Epistemological Beliefs (QEB) – Pre- and posttest Group Interviews (qualitative data)	Questionnaire on Epistemological Beliefs (QEB) – Pre- and posttest
IT Self-efficacy beliefs	IT Self-efficacy Beliefs Questionnaire - Pre and posttest	IT Self-efficacy Beliefs Questionnaire - Pre and posttest
Perceptions of Learning Environment	University Social Constructivist Learning Environment Survey (USCLES) – actual & preferred forms	University Social Constructivist Learning Environment Survey (USCLES) – actual & preferred forms
Student metacognitive skills Reflective practices Physics learning preferences	 Self Monitoring and Reflection Form (SMARF) Exit Survey Study Preferences Survey	 Exit Survey Study Preferences Survey
Demographics	Survey	Survey

Measuring cognitive outcomes - Information technology self efficacy beliefs

Skills that Studio students might be expected to learn are those related to information technology or use of computers since they are an integral part of Studio courses. Rather than an absolute measure of computer-related skills, I have elected to evaluate students' self-reported, self-efficacy beliefs about using computers.

A brief information technology (IT) questionnaire was developed from items in a pre-existing on-line Studio course evaluation questionnaire. See Appendix A.1.6. The IT Self-efficacy Beliefs Questionnaire contains eight items in two groups – four items designed to assess students' perceptions of their ability to use computers (IT Skill) and four designed to assess their confidence and perceived value in using computers (IT Confidence). The items have five-point Likert type responses ranging from strongly disagree to strongly agree. Low scores indicate low skill/low confidence and high scores indicate high skill/high confidence. Four items (2, 4, 5, and 6) are negatively worded.

The IT Questionnaire was administered in the first week of Term 1 and again in the sixth week of Term 4.

Because this instrument had not been pre-tested, the data collected from initial administration to all students was used to perform a factor analysis to confirm the existence of two hypothesised factors. Six students' questionnaire returns were incomplete, leaving 241 for analysis. Validity and reliability of this instrument are discussed in Chapter 4.

Attitudes and beliefs - epistemological beliefs

The college version of the Questionnaire on Epistemological Beliefs (QEB) was used for this study. With permission of the author, a few minor modifications were made to the wording in some items to change American vernacular or custom to an Australian equivalent. See Appendix A.1.5.

The QEB was administered to all students in the first week of Term 1, 1999, (pretest) and again in the sixth week of Term 4 (posttest). A confirmatory factor analysis of the first data set produced some concern over discrepancies between the factor structure produced and factor structures previously reported in the literature. See Chapter 2. I discuss this issue in Chapter 4. To increase the database of numbers, the QEB was administered to a further group of students from the Studio intake in 2000. This increased to 286 the number of students who had completed the questionnaire in their first week of physics classes. Two students' questionnaire returns were rejected because they were incomplete, leaving 284 for analysis.

QEB reliability and validity

The validity of the QEB rests on the ability of its dimensions to predict student learning behaviours and other outcomes supported by theory (Schommer, 1993, 1998). Issues concerning internal consistency (reliability) and construct validity are discussed in Chapter 4.

Group interviews

Interviews with small groups of SI students were conducted to investigate further their beliefs about physics and learning physics. The theoretical perspective underpinning group interview methodology is *symbolic interactionism*. It is a social psychological approach most closely associated with George Herbert Mead (1934) and Herbert Blumer (1969), both cited in Patton (1990). Naturally acute or well-informed participants are chosen because they can provide insight into a situation yet still represent prevalent views. In this study, the 12 SI students I selected for interviews were those whom I believed to be articulate and who either related well to others in the class or had previously expressed opinions on learning physics. Eleven students attended interviews:

- Interview 1: April (3 students)
- Interview 2: April (2 students)
- Interview 3: May (3 students)
- Interview 4: August (3 students)

Four main questions were posed, supported by a number of sub-questions to help students elaborate on the topic if necessary:

Question 1
Why did you choose to study physics / geophysics?

- did any of your friends also enrol?
- who supported you in your decision?
- did anyone not support it?

Question 2
What do you think physics is?

- think of some words to describe physics.
- what sort of job would today's physicist perform?
- is there anyone in any area of physics whom you really admire?

Question 3
Most people think physics is hard. Why is this?

- do you find it difficult to learn?
- what do you think people need to do to successfully learn physics?
- is the teacher's skill important?

Question 4
What are your impressions about the way in which PW101 or SOM101 are taught compared with the teaching in your other units.

- what are the positives and negatives?
- do you have a preference? Why is this?
- do you feel that you are coping?
- what would make things easier for you?

All interviews were transcribed a short time after. Field notes were also recorded at the completion of each interview.

Attitudes and beliefs - Perceptions of the learning environment

The University Social Constructivist Learning Environment Survey (USCLES) – combined Actual and Preferred forms – was administered to all SI and TI students (N = 153) who attended class in week 3 of Semester 2; 152 being sufficiently complete for analysis. See Appendix A.1.7 for the instrument.

Validation of the scales in the USCLES had not been independently reported prior to this writing, but rested somewhat on the validation of the parent instruments as well as the wide use of both (Taylor, Fraser & Fisher, 1997). The USCLES data collected in this study has been added to the pool of data held by the authors to assist in further validation of the instrument.

Attitudes and beliefs – Self-reflection

At the end of each semester, SI students hand in their 'self-reflection and monitoring forms'. Students know them as SMARFs. See Appendix A.1.8. These forms were designed by previous course teachers to help students think more strategically about their progress, in response to perceived weaknesses of students in such skills. The rationale derives from the goal of helping students to become independent, self-directed learners. If students are to take control over their learning, they should be able to reflect meaningfully about their learning behaviours and attitudes, and plan to maximise their abilities or performance in relation to their goals.

I collected these forms at the end of each semester and analysed them to gauge the extent to which students reflected meaningfully on their own performance. Three categories of reflection are reported. (See Chapter 4).

Attitudes and beliefs – students' learning preferences

To investigate the relationships between students' epistemological beliefs, cognitive outcomes and study preferences a brief survey was given to students at the start of a lecture (TI) and studio session (SI) in Semester 2. The survey, which listed 11 different study/learning activities, asked students to estimate the time that they spent on each activity type during a normal week. Students were then asked to rank all activities in order of importance to them in learning physics i.e. most beneficial to least beneficial. It was felt that students could more reliably rank their study preferences if they had first considered the time that they spent on each. Students were also given the opportunity to add another type of activity in a blank space at the bottom. See Appendix A.1.9 for the survey.

The activities listed were:

1. Reading the textbook.
2. Summarising sections from the textbook.
3. Writing answers to assignment questions.
4. Doing extra problems from the textbook or elsewhere.
5. Rewriting or copying out lecture notes.
6. Discussing your work with a lecturer or tutor.
7. Discussing your work with friends or work partners.
8. Writing up practical reports.
9. Just thinking about the physics on your own (and not at the same time as doing any of the above).
10. Reading physics which is not directly related to any of your class-work.
11. Working with an external tutor or helper.

Students in both groups are allocated marks for handing in assignments (question number 3) and SI students are allocated marks for producing summaries of textbook sections (question number 2).

Surveys were distributed to all students who attended class on the two days it was administered. Eighty-five surveys were collected from SI and TI students in matched groups; 77 were sufficiently complete for analysis, 76% of the SI group (34/45) and 61% of the TI group (43/70).

Other relevant data

Demographic data

The cover sheet of the QEB asked students for information about themselves e.g. name, age group, first language and where relevant, years of speaking English, and their results on previous tests (TEE physics and TER).

Course enrolment, retention, pass and fail rate data

An attempt was made to determine overall enrolment retention, pass and failure rates for the two streams (Studio and Traditional) over the year. Data obtained from University databases included numbers of students who enrolled, as well as students who withdrew from the course or failed to complete a unit. Students who withdrew were sent a brief exit survey

(Appendix A 1.10) to ascertain their reasons for withdrawing. In addition, data on pass and fail rates were collated.

Enrolment data reliability

There was some difficulty ascertaining the exact enrolment at any given time. A number of students did not attend any class at all because they had changed courses or were granted exemptions. Some students attended for only one week. Enrolment lists for the start of Semester 2 were particularly inaccurate because students are required to enrol for the whole year at the beginning of the year. Those who fail the Semester 1 unit often do not attend in Semester 2 but may also ‘forget’ to tender an official withdrawal (despite financial penalty). Students attending the Studio are required to ‘sign on’ each week and so this attendance data is more accurate. There is no formal record of attendance kept in either lectures or tutorials for the TI students. The data presented is as accurate as could be ascertained.

Exit Survey

As soon as I became aware of a student’s withdrawal or failure to attend tutorials I sent them the exit survey and a stamped, addressed envelope by mail. If there was no reply, a second survey was sent. If there was still no reply, no further action was taken. The return rate was 15 returns out of 30 in Semester1, and seven out of 20 in Semester 2, hence the data about reasons for withdrawing are incomplete.

3.2.9 Quality criteria - Validity

Validity relates to the theoretical aspects of the measurement process and how these aspects connect with the empirical data. It refers to the extent to which an empirical indicant measures what it purports to measure (Zeller, 1988). It is not the indicant measure that is being validated but the purpose for which it is being used that is submitted to validation processes.

Validity in quantitative research depends on careful instrument construction to be sure that the instrument measures what it is supposed to measure. The instrument must then be administered in an appropriate, standardised manner according to prescribed procedures. The focus is on the measuring instrument – the test items, survey questions or other measurement tools.

In qualitative inquiry, the *researcher* is the instrument. Validity in qualitative methods, therefore, hinges to a great extent on the skill, competence and rigour of the person doing the fieldwork. The loss in rigour, perhaps because of researcher inexperience or variability, "is more than offset by the flexibility, insight, and ability to build on tacit knowledge that is the peculiar province of the human instrument." {Guba & Lincoln (1981) cited in Patton (1990, p. 14)}

Three types of validity relevant to instruments used in this study are content, criterion-related and construct validity. Furthermore, there are issues related to internal and external validity of the study in general.

Content validity

Content validity is related to sampling adequacy. This affects primarily the two assessments of traditional physics knowledge – the Examination and Quantum Mechanics Test. The concerns are that the instruments fairly represent the physics content covered in all classes and whether it is a fair representation of the course content. Experienced teachers from the SI and TI courses set both instruments jointly. Hence the method used to ensure content validity in this instance is expert judgment.

Construct validity

Constructs are qualities that are believed to explain aspects of human behaviour. Latent variables are measures of hidden or hypothetical constructs that cannot be observed directly. Hence validation of tests must rely to a large extent on indirect evidence (Burns, 1990, p. 223). For example, all items measuring the same construct must be internally consistent, that is show good agreement with one another (see Reliability below). This may be assessed using Cronbach's alpha coefficient or a Kuder-Richardson 21 coefficient. The construct measures could be correlated with another estimate of the same construct. Factor analysis or congeneric measurement analysis also help to identify if a test is assessing an underlying quality common to all measures. Ultimately, construct validity is related to substantive theory or hypothesised relations.

Schommer argues that the validity of the QEB rests on the ability of its dimensions to predict student learning behaviours and other outcomes supported by theory (Schommer, 1993). I discuss this issue further in Chapter 4.

The USCLES uses scales from two previously validated instruments, the Constructivist Learning Environment Survey (Taylor, Fraser & Fisher, 1997) and the Questionnaire on Teacher Interaction or QTI (Wubbels, Brekelmans & Hooymayers, 1991). Relevant data from this study supporting validation of this instrument is reported in Chapter 4.

Factor analysis of the IT Questionnaire results for 241 students is also reported in Chapter 4. Pearson correlation coefficient between the two scales is given as evidence for the independence of the two constructs IT Skill and IT Confidence.

Thornton and Sokoloff (1998) provide evidence for the validity of the FMCE. The construct being measured is students' understanding of, or beliefs about, Newtonian physics. The validity of the TCE is argued on the basis that the questions were based on students' thermal physics conceptual understandings commonly reported in research literature.

Internal validity

Internal validity relates to the confidence with which one ascribes change or difference to specific experiments under scrutiny. The most important threats to this study are its longitudinal nature and confounding differences between students in the matched groups. Keeves (1998) lists threats to internal validity in a longitudinal study as unaccounted for or uncontrolled confounding variables, maturation of subjects, practice effects in testing, reliability of instruments, multiple intervention interference, instability in the subjects being measured, changes in the composition of samples, reactive interventions and lack of totally random samples. Most of these are addressed below although the study extended only eight months and not over years so it may not suffer the worst effects of a longitudinal study.

Differences in students' intrinsic interest in the subject might result in differences in motivation between the two different groups. It could be argued that first year engineering majors are not inherently interested in physics. This may be a reasonable assumption for some students but not for all. Engineering is not studied at high school and so students' expectations about the study of engineering is likely to be mostly based on their learning experiences in physics classes. They may have chosen to study 'engineering' but their prior knowledge and experience of it would have been learnt mostly as *physics*. Thus both physics and engineering majors have chosen what must be, to them, just different fields of the same subject.

Of the SI group, approximately one third were designated physics majors. Of these, only about half will actually proceed to the second year of the course. Another one third were geophysics majors, who might reasonably be expected to have the same career expectation as engineers – a practical-based vocation. However, their experience of geophysics is the same as for engineering students i.e. it is learned primarily through their study of physics prior to entering university. The remaining one third of the SI group were students in a multidisciplinary degree course. Very few of these students undertake physics with the view to majoring in it. For most, it adds breadth to their science degree, thus I would not expect them to be overly committed to the study of physics. Also included in the Studio were a small number of students undertaking computer science/physics or electrical engineering/physics double degrees, a mixture of engineering and physics. While it can be argued that there might be a small core of SI students more motivated towards physics, there might also be a small core of engineering students who regard physics in the same way. Finally, physics students enrolled in the Department of *Applied* Physics, perhaps with the expectation that they would have a more practical vocation at the end. All of this is supposition but it serves to downplay the effect that motivation might have on the design of the experiment and the analysis of results.

Epistemological beliefs are not thought to change rapidly which is why the study was planned to extend over two semesters, not one. Matched groups, selected at the end of the study, were used in an attempt to control as many relevant variables as possible. Maturation of subjects and practice effect should be the same for both groups although differential experiences of physics, geophysics and engineering students over the eight months are uncontrolled. I administered the instruments in almost all cases and gave explicit instructions in the few situations where I could not.

For qualitative data, the counterpart to internal validity is *credibility* – in part established through the competence of the researcher, their belief in the paradigm and supported by triangulation (Cohen & Manion, 1989; Patton, 1990)

External validity

Threats to external validity reduce the ability to generalise findings from the study to the wider population. The study is investigating the SI students rather than the TI students. However, the final 45 SI students in the matched group are not necessarily representative of all students who started each semester. The Exit Survey attempts to provide data to describe the withdrawing students. Other descriptive data may include all students, not just those in the matched groups.

It is also important to counteract both Hawthorn and John Henry Effects (Crowl, 1989). Both of these are distortions in data resulting from students' awareness that they are involved in a 'special' course or that they are taking part in a study. This was addressed as an issue from the beginning by making it plain to *all* students that they were involved in a study. All were given written and verbal advice that the study was about *physics learning*. I administered the first and most of the subsequent questionnaires to all students both in Studio and in the Lecture stream, and carefully avoided any mention of a comparison between different groups.

Finally, this study is not intended to generalise beyond the Studio population. I pointed out in Chapter 1 that the Studio learning environment includes the particular teachers involved and hence extrapolation beyond these to other teachers in the same Department is not defensible. This does not mean, however, that the situation cannot be replicated, but the caution is that it is an educational environment and few such educational studies have been shown to be replicable (White, 1998).

3.2.10 Quality criteria - Reliability

Reliability has to do with stability, consistency and precision of measurement. Reliability is affected by the conditions under which the assessment is conducted, the integrity of student responses, the consistency or precision with which the instrument measures what it purports to measure, and consistency of marking the assessment. Quantitative reliability estimates include 'spilt-half' reliability (correlation coefficient) or Cronbach's alpha coefficient or Kuder-Richardson-21 coefficient, both of which are internal consistency estimates.

What are acceptable reliability estimates? Crowl (1989) suggests that for achievement or aptitudes ('predicting') tests, the value should be greater than 0.8. For attitudes and opinions, where there is some uncertainty about the nature of the construct, the reliability estimate should exceed 0.7, and for personality measures, values above 0.6 may be acceptable.

For this study, quantitative estimates of reliability will accompany all data analyses. In addition, in the administration of tests, students were encouraged to respond honestly and consistently.

3.2.11 Fairness versus subjectivity or objectivity

Patton advocates 'fairness' as opposed to objectivity or subjectivity for judging the involvement of the researcher in the research process. Fairness (as in investigative journalism) has the following features (Patton, 1990, p. 481):

1. It assumes multiple realities or truths. Hence a test of fairness is whether or not both (or more) sides have been presented.
2. It is adversarial rather than one-perspective in nature. Each 'side' is presented with vigour and commitment.
3. Opportunity for the reporter to test and declare his/her own biases.
4. It is a relative criterion that is measured by *balance* rather than by isomorphism to enduring truth.

Hence, the intention is for me, as researcher and (lesser) participant in the Studio programme, to declare all biases and interest in this study and its objects and to attempt to report both sides of the 'story' with vigour and commitment.

3.3 Multidimensional scaling

> *Studying patterns of differences (the analytic approach) and differences of patterns (the systemic approach) are complementary to each other; each is based on different epistemological assumptions, and each serves to address different questions.*
>
> (Salomon, 1996, p. 369)

3.3.1 Introduction

Multidimensional scaling (MDS) refers to a class of techniques that use *proximities* among any kinds of objects or stimuli as input. A proximity is a number that indicates how similar or how different two objects are. The main output is a spatial representation, consisting of a geometric *configuration of points*, like a map, or higher-order dimensional space. Each point on the configuration corresponds to one of the objects. The configuration reflects the 'hidden structure' in the data and often makes the data easier to comprehend. The more similar the objects are, the closer they appear in the map or space, and the more dissimilar they are, the further apart they are in the map or space. It is the considered and insightful interpretation of the distribution of points that gives rise to the usefulness of multidimensional analysis techniques.

3.3.2 MDS applications

Jones and Koehly (1993) describe four different types of MDS applications: (a) *dimensional applications*, in which the researcher is interested in the number and identity of stimulus dimensions employed by the subjects in perceiving and judging a stimulus domain; (b) *data reduction*, where the interest is to reduce the complex interrelationships between stimuli represented in one or more proximity matrices to a simpler, more visualisable form; (c) *configural verification* studies, which begin with a theory or hypothesis about the pattern or shape of the MDS-derived configuration and (d) to assess *structural change* in the perception or understanding of stimuli resulting from experimental manipulation, developmental changes or some other type of intervention.

In this study, MDS is being used as a *data reduction* technique and to assess *structural differences* and *structural change* in the experimental group (SI) and control group (TI).

Basic non-metric scaling models such as Smallest Space Analysis have been used in several education studies (Bar-On & Perlberg, 1985; Salomon, 1996). In particular, Salomon used it to compare two different high school level learning environments, one of which was a technology-intensive learning environment (TILE). He compared the 'patterns' obtained before and after the introduction of a computer-intensive curriculum and found that the TILE was characterised by a close relationship between individuals' learning and social interaction.

3.3.3 MDS terminology

The various terms used in MDS are now explained, with particular reference to this study. Definitions are adapted from Cox and Cox (1994), Coxon (1982) and Kruskal and Wish (1978).

Data (input)

There are both metric and non-metric MDS techniques. Metric models use dissimilarity data that is assumed to be defined at the interval or ratio level of measurement. Non-metric models assume data at the ordinal (ranked) level of measurement. The data represent some collection of objects: in this study the objects are students' perceptions of their learning environment, epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs. In Appendix A.3.2, students' preferences for different types of physics learning activity are also used.

The data can be any type of proximity measure, that is, numbers representing judgments of similarity or difference. If data are not proximities, a common way to get them is to compute some measure of profile similarity. Correlations, for example, in the form of Pearson product moment correlation coefficients, can be regarded as proximities and analysed by MDS (Coxon, 1982; Kruskal & Wish, 1978).

Objects are designated with i or j. The proximity or data value connecting object i with object j is represented by δ_{ij}. In this study, the proximities are correlation coefficients between students' scores on different questionnaire scales or instruments. For example, if object i is 'exam result' and object j is 'belief in Simple Knowledge', then δ_{ij} is the correlation coefficient between students' examination results and their Simple Knowledge epistemological belief scores. All values of δ_{ij} are arranged in a data matrix; in this case a correlation half-matrix, since $\delta_{ij} = \delta_{ji}$.

Representation (output)

MDS plots each object in a space of variable dimensionality (i.e. one dimensional or linear, two dimensional or area, three dimensional or volume, etc). If the points are designated by x_i and x_j, then d_{ij} is the distance on the map between x_i and x_j. This distance usually means ordinary Euclidean distance. Algorithms related to plotting of points and other procedures vary between programs and will not be included in this description.

Scatter diagram

The essential concept of MDS is that the distances d_{ij} between the points on the map should correspond to the proximities δ_{ij}. The correspondence between the two is shown in a *scatter diagram*, also called a Shepard diagram. The scatter diagram shows distances versus transformed proximities (also called 'fitted distances' or 'disparities') and the function f of specified type that best fits them. If the relationship between the distances and disparities is described by a particular mathematical formula, the term *metric* MDS is used. If the relationship is of no particular function other than to maintain the rank order of proximities, the term *non-metric* MDS is used. In this study, metric MDS is used, since the correlation coefficients are interval data.

If it is initially assumed that the function f is linear, and a curve results, the data should be reanalysed using a more appropriate assumption (Kruskal & Wish, 1978).

Goodness of fit

The goodness of fit of the model map is determined with a 'stress' statistic which measures the extent to which distances and disparities conform to the function f. Stress is the square root of a normalized residual sum of squares. (Note Stress I is 'Kruskal's Stress' whereas Stress II is 'Young's Stress'. They are calculated using different algorithms). S-Stress or squared-stress is different again in that while stress is defined on distance, S-Stress is defined on squared distance (Young, 1987, p. 204).

Most computer programs employ an iterative procedure involving moving towards a minimum stress value. The *best* configuration is the one that conforms the best, that is, has the smallest possible stress. In this sense, stress is more correctly called a badness-of-fit statistic.

RSQ (R^2) is the squared correlation between the disparities (optimally scaled dissimilarities or similarities) and model distances. It is interpreted as the proportion of variance of the optimally scaled data that can be accounted for by the MDS model. The closer to 1.0, the better the fit. Young recommends that RSQ be given greater scrutiny since Stress and S-Stress do not lend themselves to clear interpretation (Young, 1987, p. 205).

3.3.4 MDS solutions

Interpretation of maps

The process of interpreting the configuration of points in the spatial map is the central step in MDS. Two basic interpretation methods are common. One is to ascribe meaning to dimensions and the other is to ascribe meaning to regions, neighbourhoods or patterns of plotted points. The dimensional solution technique, the more common of the two, is to identify lines in space, possibly at right angles to each other, such that the stimuli (points) at opposite extremes of a line differ from each other in some easily describable way. The second interpretation method involves identifying neighbourhoods or regions that have meaning due to shared characteristics, and which differ from other regions because of differentiating characteristics. One reason why this type of interpretation can reveal different data patterns from dimension identification is that its focus is primarily on small distances (large similarities) while the dimensional approach attends most to large distances (Kruskal & Wish, 1978). This study will use the second, region-interpretation method. There are numerous studies – mostly from social science and psychological research – that use a regional approach.

Dimensionality

Decisions about the number of dimensions, or *dimensionality* (R), to use are as much a substantive as a statistical question (Kruskal & Wish, 1978, p. 48). Appropriate dimensionality is that which is most helpful in representing and understanding the data, which may be different from the hypothetical, 'true' dimensionality underlying the data. Two-dimensional solutions are easier to interpret. Solutions are independent of the orientation of the axes, which have no particular significance, and so are always subject to rotation.

Dimensions in MDS are analogous to factors in factor analysis, although dimensions are based on distances in Euclidean space, whereas factors are based on angles in space.

Goodness-of-fit is an important consideration is determining dimensionality. Stress decreases as dimensionality (R) increases. A normal plot of stress versus dimensionality shows that at some value of R, stress ceases to decrease at the same rate and an 'elbow' appears in the graph. This is a useful guide to the probable dimensionality. Stress below 0.1 is favoured.

Dimensionality may be made clearer (and error level reduced) by taking the squared Euclidean distances among the rows of the proximity matrix instead of Euclidean distance. If a solution of higher dimensionality reveals no more information about the data than one of lower dimensionality, the lower dimensionality solution is favoured because it will be easier to illustrate or describe.

Identifying regions in maps

Regions or groupings of points are identified by clustering techniques, in particular with reference to the original data and research aims. Circles or loops are drawn on the map to delineate regions whose points have common characteristics. It is useful to supplement closeness in the configuration with closeness based directly on the proximities data because neighbourhoods in low dimensional space may misrepresent the data from which they were derived (Kruskal & Wish, 1978).

One technique is to join points whose proximity exceeds a threshold value. For example, for correlation proximities, lines are drawn between points which are significantly correlated or if the correlations exceed a particular value. Negative correlations can be used to differentiate between points in different regions or clusters. Separate cluster analyses can provide supplementary interpretive information. Sub-structure within regions can be clarified by doing separate MDS analyses of subsets of stimuli that are close together in space. Ultimately, the grouping may be decided subjectively as an act of creative interpretation (Kruskal & Wish, 1978).

Comparing MDS patterns

A 'Procrustes analysis' (Cox & Cox, 1994) is a technique for matching one configuration of points to another and producing a measure of the match. Essentially, the process translates, rotates and dilates (or compresses) one configuration so that it matches as closely as possible the second configuration. A 'Procrustes statistic' is a least squares measure of the minimised distances between corresponding points in the two maps. Low values indicate a close match.

3.3.5 Reliability of MDS solutions

Factors that contribute to establishing the reliability of MDS configurations are the various goodness-of-fit measures and pattern stability. It is also necessary to establish that the stress minimisation process has stopped at the lowest stress rather than at a 'local minimum'.

Pattern stability

If a MDS solution is stable, the addition or removal of a few variables should not substantially alter the pattern (Kruskal & Wish, 1978). Some small changes will be expected, particularly where some variable, say X, is highly correlated with several other interrelated variables, say A and B. It means that X will appear close to A and B in the resulting spatial map. This may have the effect of drawing A and B slightly closer together. When these two positive correlations are reversed (made negative), X will now be mapped as far as possible from both A and B. A and B may, as a result, drift slightly further apart in the configuration. The more variables there are, the more stable should be the solutions when these reversals of correlation sign are made.

Robustness of solutions

A solution should not alter substantially if one or two stimuli are deleted from the analysis. Similarly, new data should map in predictable ways. Both of these provide ways of investigating the stability, and hence, reliability of MDS solutions. A rough test is that: "in a typical situation, inferences should not be drawn that would change if points were relocated by about 10% of the diameter of the configuration" (Kruskal & Wish, 1978, p. 59). While this may be useful for two-dimensional configurations, one must refer back to original data to assess stability this way for a three-dimensional configuration.

MDS solutions of dimensionality three or greater may not *appear* alike when in fact they are because of the representation of three dimensions on a two-dimensional page. MDS solutions are invariant under rotation, reflection, translation and rescaling, thus the presentation of the solution requires careful consideration.

3.3.6 Validity of MDS solutions

Validity of MDS maps has to do with how accurately they represent the actual learning environment as perceived and experienced by students, and the extent to which the interpreter is led to make the appropriate interpretations.

Factors that contribute to establishing the validity of MDS interpretations are likely to be established through both qualitative and quantitative data analysis methods. One can assess:

- the degree of consistency between the MDS patterns and original, corresponding quantitative data (both correlational data and that on which it is based), and
- the extent to which patterns are explainable and supported by triangulated data.

Alternative explanations or interpretations will be important. Ultimately, however, it will be the reliability of each of the quantitative data sets contributing to the correlation matrix that will support or negate the validity of map interpretations.

3.3.7 Different MDS approaches

MDS, as a family of techniques, is still undergoing research and change. A brief history of the development, as described by Young (1987) is as follows. In the 1950s, Torgerson developed metric MDS for psychometric measurement. In the 1960s, Shepherd developed nonmetric MDS, following which there was a growth in the application of MDS techniques in a diverse range of disciplines. The procedure became a useful way to extract metric information from nonmetric data. Kruskal and Torgerson, working independently proposed and developed a fundamentally different nonmetric MDS process. Guttman developed a further procedure, which differed in some important details from the procedures suggested by Kruskal and Torgerson, although the commonalities existing between all three procedures were such that they all construct essentially the same map from the same data.

In the 1970s, Takane, Young and de Leeuw (1977) consolidated all separate approaches and created the first algorithm capable of either metric or nonmetric MDS, using either a weighted or unweighted model. Takane combined his cubic solution for coordinates with Young's regression solution for weights and Kruskal's least squares monotonic transformation according to the alternating least squares principles developed by de Leeuw. The resulting algorithm was called ALSCAL, an acronym for Alternating Least squares SCALing.

3.3.8 Software

The program used to analyse the data is ALSCAL, which is incorporated in SPSS 10. Advantages of this program relate to its flexibility in dealing with many data types and structures. The program minimises S-Stress rather than Stress, and uses Kruskal's Stress 1 formula.

The software used to compare two different maps is Procrustes (Cox & Cox, 1994).

3.3.9 Processing the data

The basic data processing is described here but details about each map and how I define, isolate and interpret the regions is discussed in Chapter 5.

The input proximities data for the MDS analysis are the **correlations** among selected variables. Pearson correlation coefficients are used since all data is at least interval data. Spearman correlation coefficients were used for the ordinal data used in the paper that forms Appendix A.3.2.

The correlation coefficients were entered into a series of data matrices in SPSS-10. The matrices (direct printouts from SPSS) are included in Appendix A.2.3. The initial MDS settings used were:

- Distances: Create distances from data.
- Model: Euclidean distance.
- Scaling model: Euclidean distance.
- Criteria: S-Stress convergence = 0.001, minimum S-Stress value = 0.005 and maximum iterations = 30.

One- to four-dimensional solutions were investigated, but following an examination of Shepard diagrams, and Stress and RSQ versus dimensionality plots, the data were reprocessed using a Squared Euclidean model. This resulted in improved fit statistics. The final plots are given in Chapter 5.

3.4 Review of Chapter 3

In this chapter, I have described the planned research methodology. Both quantitative and qualitative strategies will be employed. Multidimensional scaling is proposed as a method of representing visually, the interrelationships among various parameters that constitute a learning environment.

In the next chapter, I describe and analyse the comparative data provided by the various instruments and research strategies.

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CHAPTER 4: COMPARATIVE STUDY OF STUDIO AND TRADITIONAL LEARNING ENVIRONMENTS

4.1 Introduction

The purpose of this chapter is to answer Research Questions 1 – 3. The structure of the chapter will be guided by the flowchart in Figure 3.2, which shows the links between data sources and Research Questions. The chapter is in two Parts, A and B. Part A deals mostly with the comparative parts of the study, in which the Studio 'matched group' is compared with the Traditional 'matched group'. Both quantitative and qualitative data are included. Part B has been added to reduce the complexity of Part A. It contains a detailed analysis of data obtained from initial administration of the Questionnaire on Epistemological Beliefs, and explains how the epistemological belief data used in Part A was produced.

PART A

4.2 Learning outcomes

In this part, I will address the following Research Questions:

Research Question 1: What are Studio students' learning outcomes?

a. Do students in the Studio course out-perform those in the traditional course as measured by common assessment instruments?
b. Do students in the Studio course out-perform those in the traditional course as measured by concept-testing instruments?
c. Do students develop skills and confidence in using computers?

The learning or cognitive outcomes of SI and TI students include their 'traditional' physics knowledge, conceptual physics knowledge and conceptual change, and students' perceptions of their computer-related skills. In addition, I will examine the pass, fail and retention rates of students in both courses.

The instruments used in this analysis are:

For 'traditional' physics knowledge and skills:

- Semester 1 - Examination.
- Semester 2 - Test 3 (Quantum Mechanics).

For conceptual knowledge and conceptual change:

- Semester 1 - Force and Motion Conceptual Evaluation (FMCE), pre- and posttest.
- Semester 2 (SI students only) - Thermodynamics Concept Evaluation (TCE) pre- and posttest.

For computer-related skills:

- IT Self-efficacy Beliefs Questionnaire (pre- and post course).

The relevant data were collected for all students in both SI and TI courses and entered into both Excel and SPSS-8 (later updated to SPSS-10) spreadsheets. Each of these has advantages and disadvantages in terms of manipulating data and producing tables or graphs. Eventually all data was transferred to SPSS spreadsheets for statistical analysis. The IT Questionnaire data was entered into a Word document before being transferred to an SPSS spreadsheet.

Two master spreadsheets were then maintained, one for all students and the other specifically for the matched groups.

4.2.1 Traditional physics knowledge

Students' results on the various assessment instruments are shown in Table 4.1. A t-test showed that SI students gained a higher mean examination score than TI students (difference between means = 5.2%, $t = 2.33$, $p = 0.022$). There was no statistical difference between the means scores for the two groups on the Quantum Mechanics test (difference between means = 4.4%, $t = 1.47$, $p = 0.15$).

Thus, SI students performed marginally better than TI students on traditional assessment tasks.

Table 4.1. Summary of results for SI and TI students for the various instruments listed above.

	SI		**TI**		
Assessment instrument	N in sample	mean % (std dev)	N in sample	mean % (std dev)	Statistics (results of t-tests)
Semester 1 exam	45	72.9	68	67.7	t = 2.33, p = 0.022
		(12.5)		(11.0)	
QM test	43	63.2	69	58.8	t = 1.47, p = 0.15
		(15.6)		(15.1)	
FMCE pretest	39	39.0	64	40.6	Diff = 1.6, t = -0.30, p = 0.77
		(26.7)		(26.3)	
FMCE posttest	39	62.1	64	53.2	Diff = 8.9, t = 1.57, p = 0.12
		(27.2)		(28.1)	
FMCE <gain>[a]	39	0.43	64	0.27	
TCE pretest	38	69.3	NA[b]	NA[b]	
		(16.1)			
TCE posttest	38	80.0			
		(11.5)			
TCE % <gain>[a]	38	0.34			

[a] <gain> = average normalised gain (refer to text in Section 4.2.1).

[b] Not carried out for TI students as Thermodynamics is not part of their Semester 2 curriculum.

Normalised gain

This statistic is described by Hake (1998). It is used by the physics education community to compare the pretest-posttest improvement of disparate groups of students on the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992) and FMCE (Thornton & Sokoloff, 1998). Each student's pretest-posttest improvement (gain) is *normalised*, i.e. it expressed as a proportion of their maximum possible improvement. The equation is

$$normalised\ gain = (posttest - pretest)/(100 - pretest)$$

where pretest and posttest are students' individual percentage scores. The *normalised gains* are then averaged to give the *average normalised gain,* or *<gain>*.

Courses employing interactive engagement strategies have been shown to achieve *average normalised gains* in excess of 0.3 on the FCI. Courses employing traditional lecturing strategies typically achieve *average normalised gains* of less than 0.3 on the FCI (Hake, 1998). Similar results are reported for groups using the FMCE (Cummings, Marx, Thornton & Kuhl, 1999).

4.2.2 Conceptual change assessment

The pretest-posttest results on the FMCE and TCE (SI students only since Thermodynamics is not part of the TI students' syllabus) are shown in Table 4.1.

FMCE

To compare the improvement in results of both groups, an analysis of covariance was performed using the pretest scores as the covariate. The mean improvement of SI students (23.1%) was significantly greater than the mean improvement of TI students (12.6%) [$F(103,1) = 9.4$, $p = 0.003$].

TCE

The mean improvement of SI students on this instrument was 10.7%. The average normalised gain was 0.34, which was more modest than for the FMCE.

The SI course was more effective than the TI course in developing students' Newtonian conceptual knowledge. As expected, both groups improved. Using the *average normalised gain* statistic, the improvement of Studio students, (<gain> = 0.43), is about what might be expected of an group subjected to interactive engagement (IE) instructional strategies. The most appropriate data with which to compare Newtonian conceptual change using the FMCE are the RPI Studio evaluation results from Cummings et al (1999). The comparison is shown in Table 4.2:

Table 4.2. A comparison of the average normalised gains of Curtin physics classes and RPI classes using the FMCE.

	Average normalised gain on FMCE	
Classes	Curtin (1999)	RPI (1999)
Traditional classes	0.27	0.21
Experimental classes (ILD)	0.43	0.45
Experimental classes (CGPS)		0.36

ILD = Interactive Lecture Demonstrations

CGPS = Cooperative Group Problem Solving

For the TCE, SI students' *average normalised gain* (0.34) is less than their FMCE *gain,* and although they made up about one third of the possible improvement, this result is still consistent with interactive engagement methods of instruction.

4.2.3 Information technology self-efficacy beliefs

The data from administration of the IT Self-efficacy Beliefs Questionnaire to 241 students was entered into an SPSS-8 database and checked for errors. Missing data was coded as 3 – the most neutral value. Selections between the integers were coded as 2 or 4, whichever was closer, on the basis that students had expressed a positive or negative response rather than a neutral one. Negatively worded items were recoded.

Following the method of Principal Component Analysis, and using orthogonal varimax rotation, a satisfactory two-factor solution with rotation sums of squared loadings exceeding 1.9, and accounting for 53.1% of variance, was produced.

- KMO measure of sampling adequacy = 0.798
- Bartlett's Test of Sphericity: Chi-square = 392, df = 28, sig = 0.000.

The KMO (Kaiser-Meyer-Olkin) measure of sampling adequacy should be greater than 0.6 for factor analysis to proceed. Bartlett’s test of sphericity tests the null hypothesis that the population correlation matrix is an identity matrix. In this case, the null hypothesis is rejected ($p<0.000$) and the correlation matrix is suitable for factor analysis.

Three of the four highest-loading items on each factor were as hypothesised. The two factors are called ‘IT Skill and ‘IT Confidence’. See Table 4.3.

Table 4.3: Rotated component matrix for two factor solution for IT Questionnaire showing items loading >0.4.

	Factor 1	Factor 2
7. Teach friends (+)*	.760	
1. Use email (+)	.683	
8. Improved skill (+)*	.682	
2. Skilled (-)*	.580	.453
6. More positives (-)		.737
4. Prefer to write (-)		.674
3. Learn easily (+)*	.472	.613
5. Little showing (-)	.414	.575

* Hypothesized IT skill items

The internal consistency of the scale for the eight items, determined using Cronbach’s alpha, was 0.73, which is considered acceptable for attitude measurement (Crowl, 1989, p. 109). Evidence for the independence of the two factors is provided by the low correlation between them, calculated using Pearson’s correlation coefficient, $r = -0.096$, $p = 0.14$ (not significant).

The factor score weights obtained from the analysis were used to determine the initial and final scores for the students in the SI and TI groups. See Table 4.4.

Results

There was a significant difference between SI and TI students on IT Skill (initial) (difference = -0.57, $t = -2.72$, $p = 0.008$). An analysis of covariance was performed, with the initial score as the covariate, to compare the change in scores of the two groups. SI students' beliefs about their IT Skill increased significantly (difference between means = 0.73, t = -4.37, p<0.000), as did TI students' beliefs about their IT Skill (difference between means = 0.34, t = -2.22, p = 0.031). There was no difference between the groups on IT Skill (final), IT Confidence (initial) or IT Confidence (final).

Table 4.4. SI and TI students' scores on the IT Questionnaire - using the same students for pretest and posttest.

IT Factor	**SI (N = 43)** mean (st dev)	**TI (N = 59)** mean (st dev)	Diff (SI – TI)	
IT skill (initial)	3.33[b]	3.90[c]	-0.57[a]	ANCOVA
	(0.98)	(1.32)		F = 0.039
IT skill (final)	4.10[b]	4.24[c]	-0.14	p = 0.84
	(0.79)	(0.97)		R^2 = 0.173
IT confidence (initial)	4.43	4.35	0.08	F = 0.85
	(1.04)	(1.15)		p = 0.36
IT confidence (final)	4.33	4.46	-0.13	R^2 = 0.242
	(0.94)	(1.11)		

[a] t-test: Diff = 0.57 (t = -2.72, p = 0.008) - significant

[b] t-test: Diff = 0.77 (t = -4.37, p < 0.000) - significant

[c] t-test: Diff = 0.34 (t = -.2.22, p = 0.031) - significant

Discussion

On entry to the course, SI students (N=43) believed themselves to be less skilled at using IT than did TI students. By the end of the year this difference had been eliminated, however both IT and SI students believed that their skills had improved over the year. SI students reported a greater improvement.

Neither group of students reported any change in their beliefs about their confidence in, or value for, using computers in their studies.

Thus, SI students, who perceived themselves to be less skilled than TI students at using computers at the beginning of the year, appear to have made up these skills over the two semesters. It is possible that intensive involvement in the Studio course has helped them to develop their skills, although a year might be an adequate time in which to make up these skills regardless of Studio exposure. If the difference is due to involvement in the Studio, IT Skill improvement should be recognised as a cognitive outcome of the course and reflected in the unit objectives and assessment profile.

4.2.4 Student retention or withdrawal

The data used above to compare the cognitive outcomes of the SI and TI students were from the 'matched' groups only. An attempt was made, however, to determine overall retention, pass and failure rates for the two streams (Studio and Traditional) over the year. Data collected included numbers of students who enrolled, as well as students who withdrew from the course or failed to complete the unit. Students who withdrew were sent a brief exit survey (see Appendix A.1.10) to ascertain their reasons for withdrawing. In addition, data on pass and fail rates were collected.

Processing of data

All students were assigned an 'enrolment status' category as shown in Table 4.5. The descriptive data is shown in Table 4.6.

Table 4.5. Categories of students based on the status of their enrolment during the year.

Category	Description
P	A student awarded 50% or more at the end of the course
F	A student awarded less than 50% at the end of the course [a]
DNC	(Did Not Complete). An enrolled student who ceased attending class without officially withdrawing
W	A student whose withdrawal was officially notified.
C	A student who changed course, cancelled their enrolment or did not start attending (despite being on the initial enrolment lists).

[a] Some of these students may have subsequently been awarded a 'conceded pass' or may have been granted a supplementary examination which they may have passed. Because this data was difficult to access, students' submitted marks at the end of the course was used to determine their status. The actual failure rate will therefore be slightly less than that calculated by this method.

Table 4.6. Descriptive data on SI and TI student enrolment and attendance status.

	Semester1		Semester 2		Whole year		
Status	TI	SI	TI	SI	TI	SI	Ratio TI/SI
Number enrolled (E)	202	67	172	68	374	135	2.77
Cancelled enrolments (C)	17	2	38	15	55	17	3.24
Initial attendance [a] (A)	185	65	134	53	319	118	2.70
Withdrawal (W)	3	10	2	2	5	12	0.42
Did not complete (DNC)	6	0	2	1	8	1	8.00
Fails (F)	17[c]	0[c]	14	7	31	7	4.43
Passes (P)	159	55	116	43	275	98	2.80
Success rate [a]	86%	85%	87%	81%	86%	83%	1.04

[a] The best estimate of the number of students who started each unit with the intention of finishing it.

[b] Success rate is here defined as the number of passes per initial attendance (which includes withdrawals) = P/A (expressed as a percentage).

[c] In relation to initial attendance, the 'fail' rate of SI students is significantly less than TI students in Semester 1: χ^2 (I, N=17) = 6.0, $p<0.05$.

Processing attendance data

It was hypothesised that the number of P, F, W and DNC for the TI and SI groups would be in the same proportion as the ratio of TI initial attendance to SI initial attendance (i.e. ratio $A_{TI}:A_{SI}$).

Semester-long data and results

The fail rate of SI students in Semester 1 appears significantly lower than for TI students (0:17). It also appears that the withdrawal rate for SI students in Semester 1 is significantly higher than for TI students. However, the small numbers make statistical testing non-viable.

Year-long data and results

The data for W and DNC were grouped because of the small numbers. The TI data was taken as the 'correct' value and an 'expected' number determined for the SI data. A chi-square test was then conducted to determine if any ratios were significantly different from those expected. The data is shown in Table 4.7. The only data on which SI was different from TI is the combined total of W and DNC. The W+DNC rate was significantly higher for the SI group than for the TI group, χ^2 (1, N=26) = 14.0, $p< 0.05$. That is, the rate at which students withdrew from their course, or just ceased completing work, assessments or sitting the final exam, was greater for the SI course than for the TI course.

Table 4.7. Comparison of P, F and W+DNC for TI and SI students using chi-square test on whole year data.

	TI (N = 319)	SI (N = 118)	SI ('expected')	χ^2
P	275	98	102	0.16
F	31	7	11.5	1.77
W+DNC	13	13	4.81	14.0*
W+DNC+F	44	20	16.3	0.83

* $p < 0.05$

Issues arising from attendance data

Why was the failure rate of SI students so low and the withdrawal rate so high in Semester 1? Why did a greater proportion of SI students withdraw or not complete a unit? It is plausible that the two are linked. Possible explanations are:

1. SI students were sufficiently dissatisfied or disenchanted with their initial experiences in the Studio, enough to prompt them to withdraw.
2. Students withdrawing were those who thought that they might fail the unit, and this happened more for SI students than for TI students.
3. Because of greater contact with instructors, SI students confronted their problems or weaknesses earlier and this prompted their decision to withdraw rather than risk failure. TI students are able to avoid contact with instructors and because no attendance record is kept, they are not forced to confront their problems until too late.

Exit surveys

The exit surveys for students withdrawing from their course/unit for reasons that were not simply early cancelled enrolments are the only ones considered here. The return rate for surveys were:

SI:
Semester 1: six out of 10. Semester 2: one (verbal response) out of two. [The second student moved overseas with his family mid-semester].

TI:
Semester 1: two out of three. Semester 2: none out of two.

The main reasons, on the basis of percentage for each reason, are detailed in Table 4.8. The reasons involve inadequate skills or preparation for the type of unit, inability to keep up and disaffection with teaching methodology or organisation. Students 16 and 130 offer two divergent views. Student 16 (from the TI group) was repeating the unit. In the previous year he had been in the SI course but Departmental policy was to direct students to the TI course if they had previously demonstrated an inability to succeed in the SI stream. This student felt alienated in the TI stream and wanted to return to the SI course.

> *I intend to reduce my workload and re-enrol in PW101 … next year even though I still wont(sic) be allowed to attend the studio classes. If you feel it is possible that I can please send me an email S 16).*

Table 4.8. Reasons given by students on exit surveys for withdrawing from unit or course after it had started. Data does not include students who cancelled their enrolment prior to start of the unit.

Group and semester	Student	Primary reason	Secondary reason	Tertiary reason	Outcome
SI (sem1)	33	Unit (PW101) too difficult	Disliked the teaching methods	Excessive workload, no help with problems	Withdrew from course – intended to re-enrol in another course
SI (sem1)	114	Disliked the course			Withdrew from course – intended to re-enrol in another course
SI (sem1)	117	Unsure about wanting to continue course	Excessive workload	Would have preferred 'lectures'	Withdrew from both physics units – undecided about re-enrolment/course
SI (sem1)	130	Unable to keep up – inadequate prior knowledge	Disliked the teaching methods	Dissatisfaction with facilities and course organisation	Withdrew from course – intended to change institutions
SI (sem1)	169	Decision to change to another course			Withdrew from course – intended to re-enrol in the new course
SI (sem1)	223	Financial			Withdrew from course – intended to re-enrol in same course
TI (sem1)	16	Dissatisfaction with lecture teaching method	Did not get to know others in the class	Lecture times inconvenient	Withdrew from course – intended to re-enrol in same course
TI (sem1)	188	Inadequate mathematics background	Subject too difficult	Excessive workload	Withdrew from the course. Future unknown.
SI (sem2)	45	Unable to keep up with course requirements (verbal response)	Persistent ill-health		Withdrew from course – intended to re-enrol in a foreign language course

Student 130 (from the SI group) was a mature-age student who had gained course entry on a special enabling programme. She felt alienated in the Studio because of weak prior knowledge, inability to form alliances with younger students, but mostly because of a strongly held and expressed distrust of the studio teaching methods and expectations.

> *With no lectures and tutorials, and a perceived reluctance of the teaching staff to be available, this appeared to be a 'teach yourself' unit* (S 130).

The responses from students about reasons for withdrawal do not necessarily support any one of the possible explanations offered above, and so all three remain plausible at this stage. It does appear, however, that SI students are more likely than TI students to withdraw rather than continue if they have concerns about their ability or interest in their course.

4.2.5 Conclusions related to learning outcomes

- SI students developed more physics knowledge than TI students. They also made greater conceptual gains in Newtonian thinking, equivalent to the gains made in other courses using similar interactive instructional strategies.
- SI students report a greater improvement in their computer-related skills to equal that of TI students by the end of the year.
- In Semester 1, there fewer fails in the Studio course than in the traditional course, but a greater student withdrawal rate as well. The effect was no difference between the 'success' rates of both groups. The greater withdrawal rate may be related student responses to the type of instruction.
- Overall, there is no difference between the courses in pass rates and retention rates calculated over the whole year.

4.3 Perceptions of the learning environment

In this part, I will address the following Research Questions:

<u>Research Question 2</u>: What roles do Studio students' perceptions of their learning environment play in their physics learning?

a. What are Studio students' perceptions of their actual and preferred learning environment, and how are they different from those of students in the traditional course?

b. Are Studio students' perceptions of their learning environment related to their physics learning outcomes?
c. Do Studio students learn and apply self-monitoring and reflection skills?

4.3.1 University Social Constructivist Learning Environment Survey data collection

The USCLES (Appendix A.1.7) combined Actual and Preferred forms was administered to all SI and TI students who attended class in week 4, Semester 2. One hundred and fifty-three students completed the instrument, including 37 (82%) of the 'matched' SI group and 60 (86%) of the 'matched' TI group. One incomplete response was rejected, leaving 152 for analysis.

The five-point Likert scales range through Almost Always (=5), Often (=4), Sometimes (=3), Seldom (=2) to Almost Never (=1). Hence the numerical responses indicate students' perceptions of the degree or frequency that the stated 'constructivist' practices **are** experienced (Actual form) and the degree or frequency that they would **prefer** to experience them (Preferred form).

The data was entered into an SPSS database for analysis.

4.3.2 USCLES data analysis

Instrument scales

The scale reliabilities (internal consistencies), determined using Cronbach's alpha coefficient, were all between 0.71 and 0.91 (see Table 4.9), which are acceptable values for attitudinal data.

Since the option of weighting items within the scales was not warranted, the scores for the six items comprising each scale were averaged to give a final score. The six scales are *Relevance, Reflective Thinking, Negotiation, Leadership, Empathy* and *Support*.

The inter-scale correlations (discriminant validity) of the Actual scales are low enough (0.19 to 0.52) to suggest that these scales are relatively independent of one another, although there is some concern that the last three scales, *Empathy* and *Support* (helpfulness), and to a lesser extent, *Leadership*, may not be measuring completely independent constructs. This might be because the 'object' of these perceptions is the teacher. A larger range of classes with different teachers is needed to explore this issue further. The inter-scale correlations of the preferred scales are similar (0.31 to 0.50).

Table 4.9. Whole sample reliabilities and mean differences for actual and preferred forms (N=152).

Scales	**Form**	**Cronbach alpha**	**Discriminant validity**	**Scale means**	**SD**	**Mean diff/s**
Relevance	Act	0.782	0.448	2.99	0.70	-1.09***
	Pref	0.712	0.319	4.08	0.54	
Reflective thinking	Act	0.721	0.192	3.19	0.62	-0.63***
	Pref	0.778	0.380	3.83	0.63	
Negotiation	Act	0.906	0.193	3.11	0.88	-0.57***
	Pref	0.865	0.311	3.69	0.69	
Leadership	Act	0.865	0.455	3.47	0.77	-1.03***
	Pref	0.789	0.397	4.50	0.43	
Empathy	Act	0.845	0.500	3.71	0.73	-0.69***
	Pref	0.815	0.463	4.39	0.48	
Support	Act	0.892	0.522	3.42	0.83	-0.90***
	Pref	0.825	0.502	4.32	0.53	

*** $p < 0.001$

On all scales, students indicate a preference for a more 'constructivist' learning environment than was perceived to exist at the time. Similar data is reported for comparisons of actual and preferred forms of other instruments (Fraser, 1998; Fraser & Treagust, 1986).

Data

Students' Actual and Preferred perceptions of their learning environment will be described and analysed from the following viewpoints:

a. all scales considered individually;
b. scales 1-3 grouped as *Student Communication and Reflection* (SCR); and
c. scales 4-6, grouped as *Teacher Interpersonal Qualities* (TIQ).

Means, standard deviations and t-statistics are in Tables 4.10 to 4.15, and illustrated in Figures 4.3 and 4.4. Correlations between Actual and Preferred scales are in Table 4.16.

Results and discussion

Students' perceptions of their 'Actual' learning environment

SI students describe their Actual learning environment as consisting of more frequent constructivist practices than do TI students on all scales but *Reflective Thinking* (Table 4.10), where there is no difference between the two. This is an important result considering that the Studio course has in place several strategies for facilitating students' reflective practices, one of which is the 'self-monitoring and reflection' exercise that students are required to complete. It would appear that SI students do not recognise or value such strategies for what they are designed to do, and that in all likelihood; as a result, they do not carry them out effectively. This is supported by data from the analysis of SI students' self-monitoring and reflection forms. See Section 4.3.4.

Table 4.10. SI and TI students' responses to the USCLES Actual form – means, standard deviations and differences

	SI (N=37)	**TI** (N=60)			
USCLES scale	**Mean SD**	**Mean SD**	**Diff (SI-TI)**	**t-stat**	**Sig (2-tailed)**
Relevance	3.66	2.81	0.85	7.16	0.000
	0.49	0.61			
Reflective Thinking	3.28	3.18	0.10	0.81	0.421
	0.46	0.66			
Negotiation	3.70	2.95	0.75	4.76	0.000
	0.78	0.74			
Leadership	4.08	3.18	0.88	6.46	0.000
	0.56	0.80			
Empathy	4.37	3.45	0.92	7.20	0.000
	0.57	0.64			
Support	4.22	3.08	1.13	8.12	0.000
	0.64	0.68			

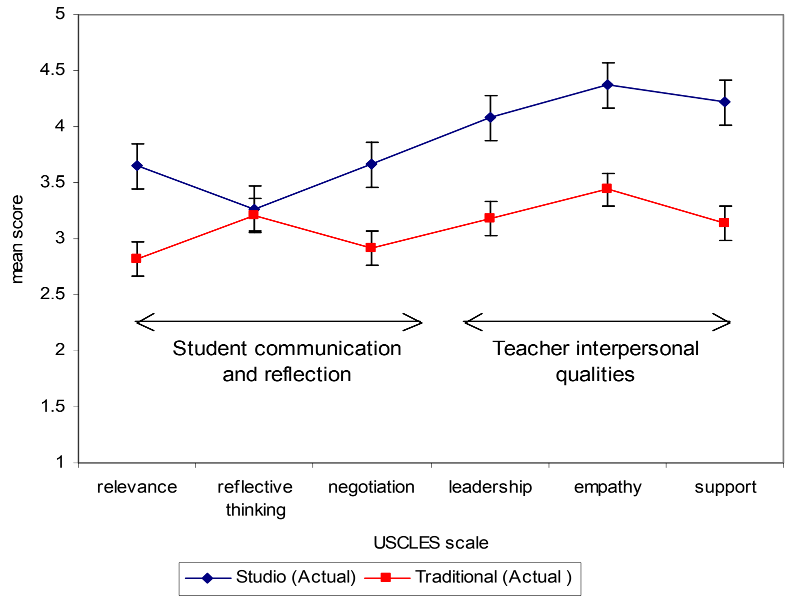

Figure 4.1. Plot showing USCLES Actual means and confidence intervals for SI (N=37) and TI (N=61) on six scales.

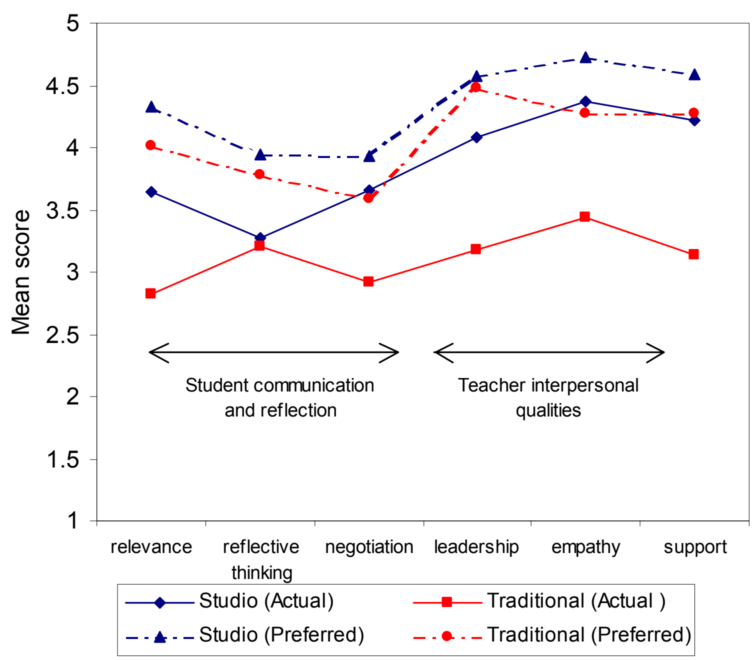

Figure 4.2. Plot showing USCLES Actual and Preferred means for SI (N=37) and TI (N=61) on six scales.

TI students' estimates of the frequency of constructivist activity on all scales range from 2.81 to 3.45. The theoretical mean of 3 signifies that the average response to 'what actually happens in this class' is 'sometimes'. Hence, TI students do not consider that constructivist practices are non-existent or even particularly low in frequency in their class. They were given the survey during tutorials and not a lecture period, and their responses may reflect their tutorial experiences, which would possibly feature more discussion and greater personal contact between teacher and students than would lectures.

Students' perceptions of their 'Preferred' learning environment

Both SI and TI students would prefer their classroom activity to consist of even more constructivist practices of the type included in the surveys than they currently experience, on all six scales. See Table 4.11.

Table 4.11. SI and TI students' responses to the USCLES Preferred form – means, standard deviations and differences.

	SI (N=37)	**TI (N=60)**			
USCLES scale	**Mean SD**	**Mean SD**	**Diff (SI-TI)**	**t-statistic**	**Sig (2-tailed)**
Relevance	4.33	4.02	0.31	3.24	0.002
	0.43	0.47			
Reflective Thinking	3.96	3.76	0.20	1.55	0.124
	0.55	0.65			
Negotiation	3.94	3.61	0.34	2.37	0.020
	0.70	0.68			
Leadership	4.57	4.46	0.11	1.19	0.207
	0.36	0.48			
Empathy	4.73	4.23	0.50	5.95	0.000
	0.35	0.47			
Support	4.59	4.24	0.36	3.48	0.001
	0.43	0.57			

Differences between Actual and Preferred learning environments

In particular, SI students would prefer the content of the course to be more *Relevant* (diff = 0.67, t=9.72, $p<0.01$) and to engage in more *Reflective Practices* (diff = 0.67, t = 9.27, $p < 0.01$). Their preference for more

Negotiation of the curriculum (diff = 0.24, t = 2.06, p = 0.046) is not as emphatic as for the other scales. TI students would clearly like the content of the course to be more *Relevant* (diff = 1.21, t = 12.5, p < 0.01), for teachers to exhibit more *Leadership* (diff = 1.29, t = 12.2, p < 0.01) and to experience more *Support* from their teachers (diff = 1.15, t = 11.3, p < 0.01). See Tables 4.12 and 4.13.

The average difference between Actual and Preferred scales is 0.46 (about half a scale unit) for SI students and 0.95 (about a whole scale unit) for TI students. The higher rating for Preferred over Actual has been found in other research where the interpretation is that the greater the difference, the more dissatisfied students are with their learning environment, and the less the difference, the more satisfied they are with their learning environment (Fraser, 1998). In this instance, it can be inferred that TI students are less satisfied with their learning environment than are SI students.

Table 4.12. Differences between SI students' responses to the Actual and Preferred USCLES forms – means and differences (N=37).

USCLES scale	Actual	Preferred	Difference (Pref-Act)	t-statistic	Sig (2-tailed)
Relevance	3.66	4.33	0.67	9.72	0.000
Reflective Thinking	3.28	3.96	0.68	9.27	0.000
Negotiation	3.70	3.94	0.24	2.06	0.046
Leadership	4.08	4.57	0.49	7.49	0.000
Empathy	4.37	4.73	0.36	3.92	0.000
Support	4.22	4.59	0.37	5.32	0.000

Table 4.13. Differences between TI students' responses to the Actual and Preferred USCLES forms – means and differences (N=60).

USCLES scale	Actual	Preferred	Difference (Pref-Act)	t-statistic	Sig (2-tailed)
Relevance	2.81	4.02	1.22	12.48	0.000
Reflective Thinking	3.18	3.76	0.58	7.39	0.000
Negotiation	2.95	3.61	0.66	6.72	0.000
Leadership	3.18	4.46	1.28	12.24	0.000
Empathy	3.45	4.23	0.78	9.15	0.000
Support	3.08	4.24	1.15	11.31	0.000

Grouped scales

The scales are grouped into two categories, Student Communication and Reflection and Teacher Interpersonal Qualities. Actual and Preferred data for SI and TI students are in Tables 4.14 and 4.15 respectively. SI students rate actual Teacher Interpersonal Qualities, consisting of *Leadership, Empathy* and *Support (or Helpfulness)*, (mean = 4.22) much higher than do TI students (mean = 3.23) ($t = 8.07$, $p < 0.000$). However, both groups would prefer more (SI mean = 4.63, TI mean = 4.31). What TI students would prefer is approximately what SI students indicate that they already have. Hence there is likely to be less dissatisfaction among SI students than among TI students with interpersonal qualities of their teachers.

Both groups rate Student Communication and Reflection significantly lower, or less important than, Teacher Interpersonal Qualities, as judged by the means scores (SI: means = 3.53 and 4.22, TI means = 2.98 and 3.23). I interpret this as students' expectations about the 'authority' of their teachers, who they regard as responsible for their learning. The teacher(s) is(are) seen as more important that the learners themselves. This is even more emphasized by the data in the Preferred scales (Table 4.15).

Table 4.14. SI and TI students' responses to the USCLES Actual form: Student Communication and Reflection, and Teacher Interpersonal Qualities – means, standard deviations and differences.

	SI (N=38)	**TI (N=60)**			
USCLES scale	**Mean SD**	**Mean SD**	**Diff (SI-TI)**	**t-statistic**	**Sig (2-tailed)**
Student Communication and Reflection	3.53	2.98	0.59	6.21	<0.000
	0.38	0.45			
Teacher Interpersonal Qualities	4.22	3.23	0.98	8.07	<0.000
	0.38	0.61			
Differences	0.69	0.25			
t-statistic	-7.30	-3.24			
Sig (2-tailed)	<0.000	0.002			

Table 4.15. SI and TI students' responses to the USCLES Preferred form: Student Communication and Reflection, and Teacher Interpersonal Qualities – means, standard deviations and differences.

	SI (N=37)	TI (N=60)			
USCLES scale	**Mean DS**	**Mean SD**	**Diff (SI-TI)**	**t-statistic**	**Sig (2-tailed)**
Student Communication and Reflection	4.08	3.80	0.28	3.24	0.002
	0.38	0.44			
Teacher Interpersonal Qualities	4.63	4.31	0.32	4.14	<0.000
	0.31	0.45			
Differences	0.55	0.51			
t-statistic	-9.91	-11.9			
Sig (2-tailed)	<0.000	<0.000			

4.3.3 Perceptions of learning environment and cognitive outcomes

Tables 4.16 and 4.17 show correlations among SI and TI students perceptions of their Actual learning environment and Cognitive Outcomes, and Preferred learning environment and Cognitive Outcomes respectively. A negative correlation means that those with higher results tend to rate the learning environment lower on the scale than those with lower results, who tend to rate it higher. A positive correlation means that those with lower results tend to rate the learning environment lower on the scale than those with higher results, who tend to rate it higher.

For the Preferred scales, there is a similar pattern. Students with lower results are the ones more strongly wanting teachers to display more *Leadership*. TI students with lower results on tests also would prefer more *Negotiation* and Teacher Interpersonal Qualities.

Table 4.16. Correlations between cognitive outcomes and perceptions of the Actual learning environment for SI (N = 37) and TI (N = 52) students. Correlations between –0.2 and +0.2 are not shown. (Pearson correlation coefficients).

	SI students				**TI students**		
	EXAM	QM test	FMCE (post)	TCE (post)	EXAM	QM test	FMCE (post)
Relevance							
Reflection			0.22			0.26	
Negotiation							
Leadership	-0.34*	-0.34*	-0.29	-0.35*			
Empathy	-0.25	-0.35*					
Support	-0.24	-0.31				-0.27*	

** p<0.01 * p<0.05

Table 4.17. Correlations between cognitive outcomes and perceptions of the Preferred learning environment for SI (N = 37) and TI (N = 52) students. Correlations between –0.2 and +0.2 are not shown. (Pearson correlation coefficients)

	SI students				**TI students**		
	EXAM	QM test	FMCE (post)	TCE (post)	EXAM	QM test	FMCE (post)
Relevance							
Reflection	-0.21	-0.27					
Negotiation					-0.32*	-0.20	-0.23
Leadership	-0.46**	-0.47**	-0.21	-0.42*		-0.24	
Empathy	-0.23		-0.29	-0.29			
Support	-0.26			-0.21	-0.30*	-0.29*	

** p<0.01 * p<0.05

Results and discussion

For SI students, there is a general negative correlation between scores on Teacher Interpersonal Qualities scales (particularly, *Leadership* and *Empathy*) and scores on traditional physics testing instruments in particular. This indicates that students with lower results tend to rate the prevalence of the type of teacher qualities or behaviour higher than do those with higher results. This is clearly evident with the scale Leadership. There is little evidence of the same trend with TI students.

A clear trend is that that physics students with lower marks, in general, want their teachers to be more proactive in directing their learning activities and in providing a more supportive, constructivist environment. For SI students, this is particularly evident for the scale *Leadership* – students with lower marks want to be told more emphatically what they should do. For TI students, the emphasis is more on *Negotiation* and *Support*.

This data supports the earlier assertion that students have expectations about the role of the teacher (authority) in their learning – however, it indicates that students with lower marks are the ones wanting more direction in their learning.

4.3.4 SI students' self-monitoring and reflection skills

SI students are required to keep a progressive record of their marks and reflective comments so that they can monitor their performance against their personally set goals. They must also write a few concluding paragraphs reflecting on their performance over the semester. I collected students' Self-Monitoring and Reflection Forms (SMARFs) each semester for analysis. See Appendix A1.8 for form.

This analysis refers only to the final reflective paragraphs that students wrote. The comments were transferred to a Word document. To make sense of the variety and detail of comments, I classified them according to what I perceive is the quality of the reflection – its value as a guide for future action or behaviour. The categories emerged from my reading and interpretation of student comments. If some students actually thought more strategically but did not write convincingly, I may have done them an injustice. Category 3 (see below) is what I would expect of a student who thinks meaningfully or metacognitively enough about their experiences to be able to benefit from the process. Table 4.18 lists a descriptor of each category as well as an illustrative excerpt from the comments of students. Table 4.19 shows the number (and percentages) in each category per semester.

Table 4.18. Descriptors and illustrative excerpts from SI students' SMARFs.

Cat	and Descriptor	Example of student comment
1	Simple or purposeless comment about achieved marks and/or performance.	… I got a bit relaxed towards the end … should do better in exam, expecting to pass, hoping for around 65 or above. *(S 12*)
2A	Simple reflection on marks or grade in relation to student's pre-determined goals.	*... At the start of the year, I set myself a goal of 70% and to go into the exam with 52% was disappointing. The main problem that I had through the year was consistent work and as a result I was struggling to pass never mind achieve my goal.* (S 109)
2B	Reflection on marks or performance in relation to general behaviours or attitudes.	*... I was overwhelmed by the amount and level of work required, one, to the amount of* [paid] *work I was getting a week (30+ hours) and the fact that I was quite disorganised. Lack of time was a huge factor in my not turning in some set pieces of work.* (S 163)
3A	Reflection on marks or performance in relation to specific attitudes, strategies or behaviours and/or pre-determined goals.	*... I started out at the start of the year with determination to do all the work and try to get an 80+ mark. However, as soon as the work began for all subjects, I began to slack firstly by doing the homework on the due date until I eventually stopped doing it altogether. It is frustrating because I felt I could get one of the top marks in the class…*(S 241)
3B	Reflection on marks and/or performance in relation to behaviours and/or attitudes with a definite or realistic resolution or action plan.	*... Upon retrospect, I can see that somewhere along the line, I let myself lose interest. Admittedly, self-motivation has never been an issue. I had, until last year, a spontaneous interest in learning. I realise now that I cannot just stubbornly depend on my curiosity to drive me, but must explore other ways of motivating myself.* (S 214)
3C	Reflection on marks and/or performance in relation to the Studio course and/or structure and/or organisation.	… I think one of the best ways of studying for a subject is to explain it to another person and the studio sessions allowed plenty of opportunity to do this. *(S 25)*

Table 4.19. Number and classification of SMARFs submitted at the end of each semester. Percentages are in brackets.

	Semester 1		Semester 2	
Number of students enrolled at the end of the semester.	51		47	
Number (%) of forms not submitted or incomplete.	13 (25%)		11 (23%)	
Category 1	6 (12%)		11 (23%)	
Category 2A	5 (10%)	}14 (28%)	3 (6%)	}14 (27%)
Category 2B	9 (18%)		11 (23%)	
Category 3A	4 (8%)	}18 (36%)	7 (15%)	}11 (23%)
Category 3B	10 (20%)		2 (4%)	
Category 3C	4 (8%)		2 (4%)	

Results and discussion

In general, the data in Table 4.19 indicate that most students (those not in category 3) did not, or were not able to, reflect meaningfully or strategically on their results and learning behaviours. Approximately one quarter of all SMARFs were not submitted or not completed each semester.

In first semester, about one third (36 percent) of students provided category 3 reflections. In second semester, about one quarter (23 percent) of students submitted category 3 reflections. The reason for the general reduction in the quality of responses between first and second semester could be that students might perceive less need to consider definite plans or strategies at the end of the year.

Most students were simply self-critical:

> *I need to work on my time management skills so as to get better next semester* (S 10)
>
> *I did not complete enough work in class* (S17)
>
> *I just need better homework habits* (S 122)

… and only a few reflected on their strengths or developing level of skill:

> *… I have found the Particles and Waves unit interesting and very challenging. It has brought to light my strong and weak points. Some strengths are participation and motivation, weak points are grasping concepts and ideas….* (S 159)

A few students attributed their ‘less than hoped for’ performance problems to the actions of teachers. For example, student 80 believed his performance would improve if given “*a more detailed explanation of concepts and formulas*.” Student 183 expected teachers to continue directing his learning and wanted to be given more lists of extra textbook problems to do:

> *The extra questions set at the start of the unit were very helpful to me, but halfway through that guidance ceased.* (S 183)

Student 14 was concerned about a perceived change of style of test questions:

> *I flunked on the relativity questions which were very different to the year before!* (S 14)

Some students’ expectations of teachers are that they will conform to teaching in ways that support how the students believe they learn best or have learned physics in the past. They focus on the role of the teacher rather than the role of the learner. The role of the teacher is to ‘teach’ and the role of the learner is to ‘do the work’.

Correspondence with USCLES results

The USCLES scale that appears most problematic for SI students is Reflective thinking (reflection) – the opportunities provided for students to reflect on their learning, which was rated lowest on the Actual scales. This finding supports the analysis of SMARFs. SI Students appear not to have adequate self-monitoring and reflection skills. Only a small number of students reported meaningful analysis or strategic decisions on future behaviour. The majority demonstrated a superficial approach to evaluation of their learning. My inference is that students have only a minimal appreciation of what self-reflection or self-evaluation means – even though they say they would prefer there to be more such activities. There is no difference between the two groups’ perceptions of the Actual situation (mean Actual values are 3.28 and 3.18 for SI and TI respectively), however, both groups believe that self-reflective activities would be useful (mean preferred values are 3.96 and 3.76 for SI and TI respectively). SI students, however, do not appear to know what this means or to make a serious attempt to carry out these activities unless directed by the teacher.

4.3.5 Conclusions related to learning environment perceptions

- SI students perceive their learning environment to consist of more constructivist activities and behaviour than TI students. The only scale on which there is no difference is *Reflective Thinking.*
- Overall, SI students are more satisfied with their learning environment than TI students. TI students are not consistent in their Actual versus Preferred views.
- Students in both groups expect and want their teachers to exert a degree of control over their learning, which appears to be more important to them than their own communication and reflection behaviours. This is more evident in students with poorer learning outcomes, in particular, SI students with poorer cognitive outcomes.
- Most SI students did not engage effectively in an exercise aimed at encouraging self-monitoring and reflection behaviours and appear to have only a superficial understanding of, or belief in the value of, such behaviour.

4.4 Epistemological beliefs

> *Students come to higher education with baggage – epistemological baggage that may help or hinder learning.*
>
> (Schommer, 1993, p. 368)

The Research Questions being addressed in this section are:

<u>Research Question 3</u>: What roles do Studio students' epistemological beliefs play in their physics learning?

a. What are students' initial epistemological beliefs?
b. Are students' epistemological beliefs related to their physics learning outcomes?
c. Are students' epistemological beliefs related to their perceptions of the learning environment?
d. Does participation in the Studio course change students' epistemological beliefs?

e. What study methods/processes do students favour?

4.4.1 Students' initial epistemological beliefs

The Questionnaire on Epistemological Beliefs (QEB) was administered to TI and SI students in the first week of Semester one and again three weeks before the end of Semester two. Readers should, at this point, consult Part B of this Chapter for a treatise on the use of the QEB in this study.

SI and TI students' initial epistemological beliefs were calculated according to the process described in Part B. See Table 4.20. SI students' initial scores on Simple Knowledge were significantly lower (more sophisticated) than TI students' initial scores (difference = 0.48, $t = -0.488$, $p < 0.01$). There were no significant differences between the two groups of students on belief in Fixed Ability/Quick Learning, Certain Knowledge and Expert Authority.

Table 4.20. SI and TI students' initial epistemological beliefs

	SI (N = 44)		**TI (N = 70)**		
Epistemological belief	**mean**	**SD**	**mean**	**SD**	**Diff between means**
Fixed Ability/Quick Learning	1.75	0.56	1.59	0.66	0.16
Simple Knowledge	2.33	0.46	2.81	0.53	-0.48**
Certain Knowledge	2.99	0.71	3.05	0.69	-0.06
Expert Authority	2.37	0.84	2.41	0.68	-0.04

** $t = -4.88$, $p< 0.01$

NB: The higher the value, the more naïve the belief.

Results

Students enrolled in the engineering course (TI students) hold more naïve beliefs in Simple Knowledge than those enrolled in physics, multidisciplinary science or geophysics (SI students). This result was unexpected in that these students have a similar educational background. It seems plausible that students' epistemological beliefs influence their course selection. There was no difference between the groups on the other beliefs.

Interview data

Instances of the four identified epistemological belief dimensions were identified in students during interviews. Some students exhibited all dimensions to some degree:

S 89:*…[teachers] might know all the formulas and all the high level maths to go with it and they can talk to you* [Expert Authority]*, or at you, for an hour, but if you are the person who is dragging behind and you want a simple explanation* [Fixed ability/Quick Learning]*, they should also be able to understand it enough to be able to give you a simple enough explanation* [Simple Knowledge]*… … I don't mind [answering questions publicly in class]. If you're wrong, you're wrong, if you're right, you're right. But at least you'll know at the end of it. You'll know what the right answer is* [Certain Knowledge].

Some students, however, *could* express more sophisticated views, indicating a range of beliefs among the few students interviewed.

S 45: *… A lot of things we learn challenge how we think about them and really I find that [for] some concepts I honestly have to … do a 'one eighty' in my thinking, and then I can understand but previously, I had no conception of* [Fixed Ability/Quick Learning]. *You know, I had the opposite conception…*

S 122: *… there's got to be some point when we can equal their [teachers'] knowledge… … I wonder how you get taught at the end when you finally, you are on the level with anyone else in the world and then you want to find that one thing more. You'd do it without a teacher.* [Expert Authority] *So I guess you can, but, I don't know how.*

S 183: It's really up to us. I mean, you [teachers] do your jobs here by teaching us [Expert Authority] *the stuff. It's our job to go home and learn it.*

S 236: *It's just getting the basic concepts of the thing first. Like if it's something we haven't learned yet, just understanding… If you can understand it, then it usually makes it a bit easier for when it gets more complex* [Simple Knowledge]. *If you miss out on it the first time, it just gets a bit harder.*

S 175: *I reckon that … physics is uncovering the truth. I reckon therefore they're just looking for one explanation that will just link everything together and will just explain everything. But, um, yeah it's hard to know what the truth is* [Certain Knowledge] *because what we kind of, what we knew yesterday could be completely different to what we know today… we used to know that the world was flat//*

S 195: *And that was the truth.*

Such comments provide some evidence for the construct validity of the four identified epistemological belief dimensions, although there may be other ways of categorising such statements.

4.4.2 Students' final epistemological beliefs and belief change

The changes in SI and TI students' epistemological beliefs over the course of two semesters was investigated using an analysis of covariance, with the initial epistemological belief scores as the covariate in each case. The change in SI students' beliefs is being compared with that of TI students' beliefs, to investigate similarities or differences. The data is presented in Table 4.21.

Results and discussion

Over the course of two semesters, TI students' mean score on Simple Knowledge increased significantly more than the mean score of SI students ($F = 11.2$, $p = 0.001$, $R^2 = 0.552$). However, *both* SI and TI students appear to have developed more naïve belief in Simple Knowledge (TI: diff = 0.20, $t = -3.81$, $p < 0.000$ and SI: diff = 0.13, $t = -2.03$, $p = 0.049$). No other differences were significant although the difference between pre and post scores for SI students on Certain Knowledge was 0.17 ($p = 0.06$). It is possible that this is a real difference (Type II error) but not statistically so because of the larger standard deviations in the measurements.

Any difference between SI and TI students cannot be attributed solely to different physics instruction. The students are in different courses and apart from their mathematics classes are exposed to different teachers and teaching methods in other subjects. They are not, however likely to experience a type of Studio/constructivist instruction in any other of their subjects.

Table 4.21. Differences between SI and TI students' initial and final epistemological beliefs. (Only students for whom both results are available were used).

Epistemological. belief	**SI (N = 44) mean (SD)**	**TI (N = 60) mean (SD)**	**Diff (SI – TI)**	
Fixed Ability/Quick Learning – init	1.75	1.59	0.16	F = 0.36
	(0.56)	(0.62)		p = 0.55 $R^2 = 0.41$
Fixed Ability/Quick Learning – final	1.83	1.67	0.16	
	(0.58)	(0.58)		
Simple Knowledge - initial	**2.34**[a]	**2.86**[b]	-0.52	**F = 11.2, p = 0.001**
	(0.45)	(0.49)		$\boldsymbol{\eta^2 = 0.10}$
Simple Knowledge - final	**2.47**[a]	**3.06**[b]	-0.59	$\boldsymbol{R^2 = 0.55}$
	(0.44)	(0.49)		
Certain Knowledge - initial	2.99[c]	3.05	-0.06	F = 2.70
	(0.71)	(0.69)		p = 0.10 $R^2 = 0.29$
Certain Knowledge - final	2.82[c]	3.02	-0.20	
	(0.64)	(0.62)		
Expert Authority - initial	2.38	2.46	-0.08	F = 0.72
	(0.84)	(0.71)		p = 0.40 $R^2 = 0.26$
Expert Authority - initial	2.40	2.35	0.05	
	(0.70)	(0.57)		

[a] Difference between means is significant, diff = 0.13, t = -2.03, p = 0.049

[b] Difference between means is significant, diff = 0.20, t = -3.81, p < 000

[c] Difference = 0.17, p = 0.06 (not statistically significant).

4.4.3 Learning activity preferences

The following analysis refers to the data collected from SI and TI students in the matched groups only. Eighty-five surveys were collected with 77 sufficiently complete for analysis, 76% of the SI group (34/45) and 61% of the TI group (43/70). These are the students who attended class on the particular day.

Processing of learning activity preference data

The 'time' data was considered unreliable because students' estimates of time spent on learning for the unit PW101 varied from a few hours to more than 20 hours per week. The ranking data was essentially intact and appeared reliable, however because of the low proportion of each group responding, the data has been pooled for some analyses.

Three study activities, *writing practical reports*, *working with an external helper/tutor* and '*other'*, were deleted from the list of 12 because they were not relevant to all the students. The remaining items were ranked one through nine. Some students did not rank all activities. For missing data, the following ranks were inserted: If the highest rank recorded was 4, all unranked activities were ranked 7. If the highest rank recorded was 5 or 6, all unranked activities were ranked 8. If the highest rank recorded was 7 or 8, all unranked activities were ranked 9. This occurred for seven students.

Hence, ranks from one to five are considered reliable, but there is an element of uncertainty in the rankings with higher numbers. It might also be argued that these will also be less reliable because once students have selected their 'favourite' activities, others may all be less important to the extent that students are unable to give a meaningful rank. No student recorded *one-to-nine* down the page and all who completed surveys appear to have submitted considered responses.

Table 4.22 contains the following descriptive data for SI and TI students: mean rank (average rank for that activity), overall rank order (based on mean rank) and percentage of students who ranked the activity as their first OR second preference.

Correlations among students' ranks for the different types of activities were produced. See Table 4.23. Spearman's rho is used because the ranks are ordinal data. Data was checked for linearity and outliers. Two outliers in *answer assignment questions* were identified and later removed, but this produced no subsequent substantial change to the statistics.

Table 4.22. Study activity data: mean rank, average rank order (based on mean rank) and percentage of students who ranked the activity as their first or second preference.

Activity	**SI (N = 34)** mean rank	rank order	% ranking activity 1or2	**TI (N = 43)** mean rank	rank order	% ranking activity 1or2
Do assignment questions	2.2	1	65	2.3	2	63
Summarise textbook sections	2.8	2	68	5.7	6	12
Read the text book	3.4	3	32	2.2	1	70
Discuss with friends/partners	4.4	4	9	4.9	4	16
Think about physics (additional to above)	5.7	5	15	6.4	8	12
Do extra problems	6.2	6	3	4.4	3	9
Rewrite/copy lecture notes	6.6	7	3	5.6	5	14
Discuss with lecturer/tutor	6.7	8	3	6.1	7	2
Read extra/beyond class-work	7.1	9	3	7.5	9	2

Results and discussion

For TI students, the most valued learning activities are *reading the textbook* and *doing assignment questions*, both of which might be considered traditional activities for learning physics For SI students, the most valued study/learning activities are *doing assignment questions, summarising textbook sections* and to a lesser extent *reading the textbook*. SI students highly value the activity of summarising their textbooks as a way of learning. Sixty eight percent of SI students ranked this activity 1 or 2 whereas only 12% of TI students did. SI students are awarded up to 7% of their marks for handing in summaries and many appear to now value it as a way of learning.

A similar but low proportion of students in each group value *extra reading beyond class-work* or *thinking about physics* as ways of learning, although 15% of SI students rank *thinking about physics* 1 or 2. It appears that most students do not believe that these activities can or do contribute much to their physics learning.

Table 4.23. Correlations and 2-tailed significance among students' ranks of learning activity preferences: SI (N = 34) and TI (N = 43) (Spearman's rho). Correlations of 1.00 (on the diagonal) have been omitted for clarity.

Activity	**Read text book**		**Do ass/t questions**		**Rewrite/ copy notes**		**Do extra problems**		**Sum/rise textbook**		**Discuss w/lecturer**		**Discuss w/friends**		**Think ab/t physics**	
	SI	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**
Read text book																
Do ass/t questions		-.35*														
Rewrite/ copy notes			.42*													
Extra problems				.32*												
Summarise textbook																
Discuss w/lecturer									-.34*							
Discuss w/friends					-.41*	-.32*		-.41**		-.30*	-.34*					
Think ab/t physics		-.36*	-.46**		-.38*	-.32*		-.40**		-.34*		-.37*				
Read extra physics						-.38*	-.53**	-.34*		-.40**	-.36*				.50**	

** significant at 0.01 level * significant at 0.05 level

A positive correlation between two activities means that students who rank one of the activities highly tend to rank the other highly as well, and vice versa. There are only three significant **positive** correlations. TI students who value *doing assignment questions* as a way of learning, tend to value *doing extra problems from the textbook* or elsewhere. SI students who value *doing assignment questions* as a way of learning, tend to value rewriting/copying notes. SI students who value *thinking about physics* as a way of learning also tend to value *reading physics beyond the class-work*. There appears to be a small core of SI students who believe these last two activities to be highly beneficial to their learning.

The **negative** correlations are more numerous. Their location in the table indicates that, in general, students who value *rewriting or copying lecture notes, doing extra problems, summarising the textbook* and *discussing work with lecturers/tutors* do not tend to value *discussing with friends, thinking about physics or reading physics beyond class-work* and vice versa. It seems reasonable that the first mentioned activities are ones that students perceive to be more likely to earn them higher marks on traditional tests or exams. These activities also reflect the ‘authority’ of physics knowledge – i.e. that physics knowledge resides in ‘the’ textbook, the notes that are ‘given’ in class, the problems that mirror class work and in the mind of the lecturer, rather than represent the personal construction of knowledge that might be engendered by the latter three activities.

While both SI and TI students exhibit these negative correlations, there is more evidence that TI students react this way because there are twice as many negative correlations for TI students as SI students. It is, however, a tentative assertion because of the less than ideal return rate of questionnaires.

Summary of results on learning activity preferences

Different patterns of student learning and study behaviour are evident in these data. Most students appear to conform to, or be constrained by, traditional, structured activities such as doing assignment questions, reading the textbook or doing extra problems and tend to shun either solitary or collaborative activities that might serve more elaborative, explanatory or exploratory purposes. The data, however, suggest that some SI students have developed an alternative pattern of learning activity preferences with less emphasis on the activities that lead directly to exam or test practice and more on activities that favour the personal construction of knowledge. They appear to regard some of these less traditional activities as viable, alternative strategies. In particular, there is a high correlation among SI students who favour *read extra physics* and *think about physics*, and similarly, among those who do not favour either. TI students, on the other hand, retain a preference for a more narrow range of traditional learning activities.

Summary of conclusions from Parts 4.4.1 to 4.4.3

- At the start of the year, SI students held less naïve beliefs in Simple Knowledge than did TI students. There were no differences between the groups on the other epistemological belief dimensions. Both groups were most naïve in belief in Certain Knowledge and least naïve in belief in Fixed Ability/Quick Learning.
- Both groups retreated to a more naïve position on Simple Knowledge during the year, with TI students retreating more than SI students. SI students may have developed less naïve beliefs in Certain Knowledge during the year.
- Both groups consider *doing assignment questions* highly beneficial for learning physics. TI students favour the more passive activity of *reading the textbook*, whereas SI students favour the more elaborative activity of *summarising the textbook*.

TI students focus on activities that mirror those modelled in class – solving problems and learning for tests and exams. SI students overall have a wider, more variable range of learning activities that they consider viable. More value is placed on *thinking* activities.

4.4.4 Relationship between epistemological beliefs and learning preferences

To investigate possible links between students' learning preferences and their epistemological beliefs, correlations among student rankings of these activities and epistemological beliefs were calculated for each group. Students' 'final' epistemological beliefs were used in the analysis. See Table 4.24. Correlations between -0.2 and +0.2 are not shown.

The data in this analysis should be viewed with some caution since the number of SI students (34 = 76%), and TI students (43 = 61%) in particular, may not be representative of all students in each group.

A **negative** correlation means that the more naïve the belief (higher numerical value), the more students favour the particular activity (lower numerical rank). A **positive** correlation means that the less naïve the belief (lower numerical value), the more students favour the particular activity (higher numerical rank). A **positive** correlation also means that the more sophisticated the belief, the more students favour the particular activity, since epistemological beliefs are on a continuum scale.

Table 4.24. Correlations among students' epistemological beliefs and study/learning preference rank, for SI students (N = 34) and TI students (N = 43), using Spearman's rho correlation coefficient. Correlations between –0.2 and +0.2 are not shown.

	Fixed Ability/Quick Learning		**Simple Knowledge**		**Certain Knowledge**		**Expert Authority**	
Activity	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**	**SI**	**TI**
Read the text book	0.26			-0.32		-0.34*		-0.26
Rewrite/copy lecture notes	-0.22	-0.30	-0.22	-0.46**		-0.27		
Do assignment questions	-0.25		-0.47**				0.21	
Do extra problems		0.20	0.25					
Summarise textbook sections		0.29			0.33			-0.23
Discuss with lecturer/tutor	0.20							
Discuss with friends/partners								
Think about physics (additional to above)		-0.20	0.37*		-0.25	0.41*		0.27
Read extra/beyond class-work		-0.20						

** = significant at 0.01 level   * = significant at 0.05 level

Results and discussion

There are few significant correlations, with belief in Simple Knowledge and Certain Knowledge seemingly having the greater impact on preference for learning behaviour.

The more that SI students believe (naïvely) in Simple Knowledge, the more likely they are to value *doing assignment questions* and the less likely they are to value *thinking about physics* as a way of learning physics. The more that TI students believe (naïvely) in Simple Knowledge, the more likely they are to value *rewriting/copying lecture notes*.

Two interesting effects are noted for TI students. The more that TI students believe (naïvely) in Certain Knowledge, the more likely they are to value *reading the textbook*, and the less likely they are to value *thinking about physics*.

Hence, students with more naïve beliefs in Simple and Certain knowledge tend to favour pragmatic or traditional learning activities. The converse also holds i.e. the more sophisticated their beliefs in Simple and Certain Knowledge the less likely they are to favour pragmatic or traditional learning activities and the more likely they are to believe that reflective activities such as *thinking about physics* are more beneficial to them. The difference between the two groups is mainly in the type of traditional activity that students with more naïve beliefs favour.

It would thus appear that students with more naïve epistemological beliefs about the nature of knowledge tend to favour conventional, 'doing' activities for learning physics. Such activities are doing assignments, reading the textbook or rewriting notes. Students with less naïve epistemological beliefs about the *simplicity or certainty of knowledge* do not favour activities such as these, and place a higher importance on 'thinking' activities.

This then leads to the question – are more sophisticated or constructivist beliefs about the nature of knowledge, and different types of preferred learning activities linked to better or worse physics learning outcomes?

4.4.5 Relationships between learning preferences and cognitive outcomes

Correlation coefficients (using Spearman's rho) were calculated among students' learning preferences and cognitive outcomes. See Table 4.25. Correlations between 0.2 and –0.2 are not shown.

A **positive** correlation means that students who have higher cognitive outcomes tend to express a low preference (higher numerical rank) for the activity, and a **negative** correlation means that students who have higher cognitive outcomes tend to express a high preference for the activity (lower numerical rank).

Results and discussion

In general, positive correlations are located towards the top of the table (4.25) and negative correlations toward the bottom. Six positive correlations are significant. These correlations are limited to activities such as *rewrite/copy lecture notes* and *do assignment questions* for SI students. This implies that SI students who tend to favour these activities for learning physics have lower cognitive outcomes and those who tend not to favour these activities have higher cognitive outcomes.

There were no statistically significant correlations for TI students.

Hence, SI students who favour traditional, structured learning activities are the ones who tend to have low examination scores and those who do not prefer these activities tend to have higher exam scores. The same trend may exist for TI students but the relationships are weaker.

4.4.6 Relationship between epistemological beliefs and cognitive outcomes

The following questions are being addressed in this part.

1. Are cognitive outcomes, as measured by traditional tests and by concept-testing instruments, and skill and confidence in using technology, related to students' epistemological beliefs?
2. If so, are naïve beliefs associated with better performance or are sophisticated beliefs associated with better performance? Is there a difference between SI and TI students in this regard?

Table 4.25. Correlations between SI and TI students' study preferences and cognitive outcome measures (Spearman's rho correlation coefficient). Correlations between –0.2 and +0.2 are not shown.

Cognitive assessment test / Study preference	SI				TI		
	FMCE posttest (N = 34)	EXAM (N = 34)	QM TEST (N = 34)	TCE (N = 31)	FMCE[a] posttest (N = 43)	EXAM (N = 43)	QM TEST (N = 43)
Read the text book						0.27	
Rewrite/copy lecture notes	0.48**	0.46**	0.24	0.44*	0.22	0.30	
Do assignment questions	0.39*	0.41*	0.40*		-0.21	-0.21	
Do extra problems		-0.32				-0.22	
Summarise textbook sections			-0.25				-0.21
Discuss with lecturer/tutor							
Discuss with friends/partners				-0.37*			
Think about physics	-0.23	-0.30			-0.21	-0.29	
Read extra/beyond class-work	-0.20						

** $p < 0.01$ * $p < 0.05$

Note: A positive correlation means that greater preference for the particular study activity is associated with lower test scores and lesser preference for the particular study activity is associated with higher test scores.

Pearson coefficients were calculated for SI and TI students' final epistemological beliefs, FMCE posttest score, Semester 1 examination result, Test 2 (Quantum Mechanics) result and IT Skill (final) and IT Confidence (final). I felt it more appropriate to use final epistemological beliefs for assessments because some beliefs had changed, albeit in only a small way, over the year. The data are presented in Table 4.26. Correlations between 0.2 and –0.2 are not shown.

Results and discussion

All of the significant correlations are **negative** – that is, the more naïve the belief, the lower the result on the particular test. This also suggests that more sophisticated, constructivist beliefs are associated with better scores on various tests – both of problem and conceptual understanding types.

The association between epistemological beliefs and cognitive outcomes is not particularly strong for either group, nor is it general across all belief dimensions. The exception is belief in Simple Knowledge for SI students. Belief in Simple Knowledge is the one factor that is consistently (negatively) correlated with cognitive outcomes, which supports the existence of a causal link between the two.

Summary of conclusions from Parts 4.4.4 to 4.4.6

- Students with more naïve beliefs in Simple and Certain Knowledge tend to favour a narrow range of traditional 'learning by doing' activities such as *doing assignment questions* and *reading the textbook.* Those with more sophisticated beliefs tend to favour a broader range of learning activities including those that are less traditional and more oriented towards broader knowledge construction.
- Of the students holding more sophisticated beliefs in Simple and Certain knowledge, TI students tend to favour more extensive variations of the same type of traditional activity (assignments and extra problems) whereas SI students tend to favour more diverse 'thinking' activities.

Table 4.26. Correlations between SI and TI students' epistemological beliefs and their scores on different tests; using Pearson correlation coefficient (r).

		SI students				TI students			
Epistemological belief		Fixed Ability/Quick Learning	Simple Knowledge	Certain Knowledge	Expert Authority	Fixed Ability/Quick Learning	Simple Knowledge	Certain Knowledge	Expert Authority
FMCE posttest	r		-0.41**				-0.29*		-0.21
	N		41				65		65
Semester 1 examination	r		-0.33*					-0.29*	
	N		45					58	
Quantum Mechanics test	r		-0.39*		-0.28				
	N		43		43				
TCE posttest (SI students only)	r		-0.20		-0.26	NA	NA	NA	NA
	N		38		38				
Perceived IT Skill (final)	r						-0.25		
	N						60		
Perceived IT Confidence (final)	r						-0.33**		
	N						60		

** = significant at 0.01 level   * = significant at 0.05 level

- There is a clear trend showing that SI students who favour traditional learning activities have lower cognitive outcomes and those who tend not to favour these activities have higher cognitive outcomes. There is only tentative evidence that the same applies to TI students.
- SI students holding more naïve beliefs in Simple Knowledge and Expert Authority tend to have lower cognitive outcomes. TI students holding more naïve beliefs in Simple Knowledge and Certain Knowledge tend to have lower cognitive outcomes.

4.4.7 Relationship between epistemological beliefs and perceptions of the learning environment

Correlations among students' perceptions of their Actual learning environment, Preferred learning environment and their epistemological beliefs were determined. This involved correlations among the six USCLES scales (Actual and Preferred) and four epistemological belief scales. The data are shown in Table 4.27 (Actual) and Table 4.28 (Preferred).

A **negative** correlation means that those with more naïve beliefs tend to rate the Actual or Preferred learning environment lower on the scale than those with more sophisticated beliefs, who tend to rate it higher. A **positive** correlation means that those with more naive beliefs tend to rate the Actual or Preferred learning environment higher on the scale than those with more sophisticated beliefs, who tend to rate it lower. Correlations between –0.2 and +0.2 are not shown

Table 4.27. Correlations between epistemological beliefs and perceptions of the Actual learning environment for SI (N = 37) and TI (N = 52) students. Correlations between –0.2 and +0.2 are not shown. (Pearson correlation coefficients).

	SI students				TI students			
	Fixed Ability / Q/Learning	**Simple Knowledge**	**Certain Knowledge**	**Expert Authority**	**Fixed Ability / Q/Learning**	**Simple Knowledge**	**Certain Knowledge**	**Expert Authority**
Relevance		-0.29			-0.39**			
Reflection				-0.33*	-0.23	-0.34*	-0.24	
Negotiation	-0.35*		-0.30					
Leadership	-0.40*			0.56**				
Empathy		-0.25						
Support						-0.23	-0.22	

** p<0.01 * p<0.05

Table 4.28. Correlations between epistemological beliefs and perceptions of the Preferred learning environment for SI (N = 37) and TI (N = 52) students. Correlations between –0.2 and +0.2 are not shown. (Pearson correlation coefficients).

	SI students				TI students			
	Fixed Ability / Q/Learning	**Simple Knowledge**	**Certain Knowledge**	**Expert Authority**	**Fixed Ability / Q/Learning**	**Simple Knowledge**	**Certain Knowledge**	**Expert Authority**
Relevance		-0.33*						-0.20
Reflection	-0.27				-0.29*			
Negotiation	-0.34*		-0.25	0.21	-0.24			
Leadership	-0.30			0.38*	-0.36**			
Empathy	-0.32		0.20	0.29	-0.25	0.38**		
Support	-0.20				-0.25			

** p<0.01 * p<0.05

Results and discussion for Section 4.4.7

Actual learning environment

- All but one of the correlations of any magnitude in Table 4.27 are negative. This implies that students, both SI and TI, holding more sophisticated beliefs tend to rate the LE higher than those with more naïve beliefs, who tend to rate it lower. The exception is SI students' beliefs in Expert Authority – those with more naïve beliefs tend to rate Actual Leadership higher than those with more sophisticated beliefs.

- TI students with more naïve beliefs in Fixed Ability/Quick Learning tend to perceive the physics to be of lower *Relevance*. In other words, TI students who believe that ability cannot be changed and learning is quick or not at all, may not see it as important that the physics be relevant to them. On the other hand, SI students with more naïve beliefs in Fixed Ability/Quick Learning tend to perceive a lower degree of *Negotiation* or *Leadership*. They perhaps do not see that negotiation or leadership are relevant if ability cannot be changed and learning is quick or not at all.

Preferred learning environment

- There is a clear trend for all students holding more naïve beliefs in Fixed Ability/Quick Learning to want a less constructivist environment on all scales except Relevance. The same trend is evident for both groups. The inference is that if students tend to believe ability is innate and that learning occurs quickly or not at all, they want fewer constructivist activities, i.e. they would prefer a more 'instructivist', teacher-centred environment, where the teaching role is firmly ascribed to the teacher. Students who thus believe ability is not innate and that learning is a slow process of building knowledge therefore would prefer more frequent constructivist activities i.e. activities that help them to build knowledge in a variety of ways.

- The more SI students believe (naïvely) in the role of Expert Authority in imparting knowledge, the more Leadership constructivist activity they would prefer, and the more they believe in knowledge being developed by individuals and not handed down by 'authority' the less they feel the need for Leadership (and to a lesser extent, Negotiation and Empathy). This same recognition of, and desire for, authoritative leadership is not evident for TI students.

- The more that TI students believe (naïvely) in the Simplicity of Knowledge, the more they would prefer that teachers express a degree of empathy towards their efforts in learning.

PART B

The purpose of this section is to describe the way in which data from the Questionnaire on Epistemological Beliefs (QEB) was analysed and adapted for use in this study. A number of concerns that surfaced during data analysis eventually prompted me to derive a modified factor structure. These concerns were the minor discrepancies in factor analyses reported in the literature, the nature of this population compared with those in other studies, and anomalies in my initial data analysis.

4.5 Review of Schommer's work

4.5.1 Epistemological belief dimensions

Schommer (1990) proposed five more or less independent epistemological belief dimensions based on others' research on students' attitudes towards learning and knowledge. For example, one dimension is belief in the *certainty of knowledge*. Schommer hypothesised that individuals could demonstrate this belief in two ways – by believing in ultimate, unchanging and knowable truths (*knowledge is certain*) and by avoiding or disliking situations in which ambiguity is evident (*avoid ambiguity*). The QEB is composed of 12 subsets of items assessing individuals' preferences for statements about knowledge and learning related to these five dimensions See Tables 2.7 and 2.8. The item subsets, stated from the naïve perspective, assert that knowledge is certain (CERT), success is unrelated to hard work (WORK), individuals can't learn how to learn (LEARN), and the ability to learn is innate (INNATE). The process of learning is quick (QUICK), occurs with the first effort (FIRST), and that concentrated effort is a waste of time (EFFORT). The learner should avoid integrating material (INTEG), should seek single answers (SINGLE), avoid ambiguity (AMBIG), depend on authority (DEPEND) and avoid criticising authority (CRIT).

Each item is scored on a five-point Likert scale ranging from strongly disagree [1] to strongly agree [5]. Twenty six of the 63 items are negatively worded. Naïve believers agree with positively worded items and disagree with negatively worded items. The scores range from low (sophisticated beliefs) to high (naïve beliefs), i.e. the more naïve the belief, the higher the score.

Individuals' average scores on each of the12 subsets have been subjected to confirmatory factor (Schommer, 1993, 1998) analysis resulting in four orthogonal 'second order' factors, i.e. belief in:

1. Fixed Ability (ranging from ability to learn is fixed at birth to the ability to learn can be changed).
2. Simple Knowledge (ranging from knowledge is unambiguous, isolated bits of information to knowledge consists of complex, highly interrelated networks).
3. Quick Learning (ranging from learning is quick or not-at-all to learning is gradual).
4. Certain Knowledge (ranging from knowledge is absolute and unchanging to knowledge is evolving).

These are called 'second order' factors because they result from factor analysis of pre-determined subsets of items, not from factor analysis of all 63 items.

Neither Schommer nor subsequent researchers have identified the fifth hypothesised dimension, belief in Omniscient Authority – but the dimension was expected to range from knowledge is owned and handed down by authority figures to knowledge is developed by individuals through interaction with others.

4.5.2 Epistemological belief continua

The continua of epistemological belief dimensions are thus from *naïve* to *sophisticated*. An alternative conceptualisation is that the continuum is from *empiricist* to *constructivist*. Physics education researchers Hammer (1994) and Roth and Roychoudhury (1994) recognised this in their studies of physics students' epistemological attitudes. Roth and Roychoudhury referred to objectivism as students' 'default epistemology'. Students' epistemological beliefs have been thought of as naïve if they are undeveloped, undifferentiated or immature, however, they also fit the description of a traditional empiricist (neo-positivist) epistemology. The sophisticated position fits at least a socio-cultural constructivist, if not a radical constructivist, epistemology. Table 2.1 (Chapter 2) summarises these and other epistemologies. I will continue to use the terms *naïve* and *sophisticated* for extremes of epistemological belief dimensions but will make use of the apparent correspondence between naïve and objectivist positions, and sophisticated and constructivist positions.

4.5.3 Five unresolved issues

Five issues about research on epistemological beliefs that have been of concern to me are outlined below:

1. Five factors were hypothesised by Schommer, but only four have consistently emerged, despite phenomenological studies reporting that science students in particular defer to a higher authority when making decisions about knowledge and learning (Hammer, 1994; Roth & Roychoudhury, 1994). The two item subsets for the hypothesised dimension Omniscient Authority have remained in the questionnaire and the two item subsets, CRIT and DEPEND load onto other factors.

2. A study by Qian and Alvermann (1995) on 212 high school students identified only three factors. In their study, items for the hypothesised dimension of Omniscient Authority were deleted leaving a 53-item questionnaire. Following exploratory factor analysis, items loading less than 0.3 were deleted leaving 31 items contributing to the data. From this, only three factors emerged, Simple-Certain Knowledge, Quick Learning and Innate Ability.

3. Two strongly loading item subsets do not load as hypothesised by Schommer in her original theoretical formulation of belief dimensions. The item subset LEARN loads strongly with the item subsets for Innate Ability rather than with item subsets for Quick Learning. The item subset AMBIG loads strongly with the item subsets for Simple Knowledge rather than with the item subsets for Certain Knowledge. This has not been explained.

4. No ‘first order’ factor analysis of all 63 items has been published.

5. There remains the issue of whether all five hypothesised dimensions, or the three or four emergent dimensions fall within an accepted definition of epistemological beliefs. Hofer and Pintrich (1997) suggest that the core content of the construct of epistemological beliefs be limited to individuals’ beliefs about the *nature of knowledge* (consisting of *certainty of knowledge* and *simplicity of knowledge*) and the *process of knowing* (consisting of

source of knowledge and *justification for knowing*) thus omitting 'peripheral' beliefs related to learning, intelligence and teaching. Two of Schommer's dimensions fall outside this definition of epistemological beliefs: individuals' beliefs about the *control* and *speed of knowledge acquisition* i.e. Innate Ability and Quick Leaning.

4.5.4 Population

Schommer (personal communication, 1999) provided three factor score matrices from three different populations – American high school students, college students and adults. The proviso was that I should apply the supplied factor scores to an equivalent population. The closest was white, middle-class American college students. This created a dilemma because the students in this study were entering the equivalent of college but whether considered college level or high school level is debatable. Some were also mature age students or adults. In addition, Australian university students are not necessarily equivalent to those in American colleges or universities. This university has a significant immigrant or temporary resident student population in physics and engineering classes. Approximately one third of the engineering students are from South-East Asian or Middle-Eastern ethnic origins although an unknown number are resident in Australia.

For this study, the college level version was used. With permission of the author, a few minor modifications were made to the wording in some items to change American vernacular or custom to an Australian equivalent.

4.6 QEB data collection and analysis

4.6.1 Administration of QEB

The questionnaire on Epistemological Beliefs (QEB) was administered to all SI and TI students (N=247) in the first week of semester 1, 1999 and again three week before the end of semester 2. A confirmatory factor analysis of the initial data set produced some concern over discrepancies between the factor structure produced and factor structures previously reported in the literature. See Chapter 2. To increase the size of the database, the QEB was administered to a further group of students from the Studio intake in 2000. This increased to 286 the number of students who had completed the questionnaire in their first week of physics classes at the beginning of first semester. Two questionnaires were rejected because they were substantially incomplete, leaving 284 questionnaires available for analysis.

4.6.2 Preliminary data analysis

The data was entered into an SPSS8 (later upgraded to SPSS10) database, and checked for errors. Negatively worded items were recoded. Missing data was coded 3 – the most conservative value. Selections between the integers were coded 2 or 4 whichever was closer.

In view of the issues outlined previously, I conducted a confirmatory factor analysis of the initial data set (N=247) with the 12 subsets of items as variables. Following the method of Principal Component Analysis with orthogonal varimax rotation, a four-factor solution with rotation sums of squared loadings exceeding 1.0, and accounting for 57.6% of variance, was produced.

- KMO measure of sampling adequacy = 0.725.
- Bartlett's test of sphericity: Chi-square = 556, df = 66, sig = 0.000.

The factor structure resembled that of Schommer's college-level populations but with some inconsistency. A second factor analysis was conducted with the larger data set (N=284), but the same inconsistencies remained. For a comparison, see Tables 2.9 to 2.11 and Table 4.29. The factor Quick Learning could not be identified, but a factor more like the hypothesised dimension Omniscient Authority emerged – based on the high loading of *Depend on authority*.

Table 4.29. First factor structure emerging from this study with loadings > 0.4 shown (N=284).

Subset dimension	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Success is unrelated to hard work	0.75			
Learning is quick	0.66			
Ability to learn is innate	0.64			
Learn first time	0.60		0.40	
Can't learn how to learn	0.58		0.46	
Avoid integration		0.69		
Don't criticize authority		0.69		
Seek single answers		0.63		
Avoid ambiguity		0.62		
Concentrated effort is a waste of time			0.69	
Knowledge is certain			-0.65	
Depend on authority				0.88

Of more concern, however, was the low internal consistency of the 12 scales. See Table 4.30. Removal of some items would improve the reliability of most scales, but not to an acceptable level. The low and/or inconsistent loading of the subsets DEPEND and EFFORT in Schommer's different factor structures (see Tables 2.9 to 2.11) may indicate a low internal consistency of these two scales in other studies. No individual scale internal consistencies are reported in the literature. Given this situation, I considered it inappropriate to pursue the planned process of determining four epistemological belief scores for students based on the recommended factor score structures, and instead chose to refine the scales using congeneric modelling.

Table 4.30. Preliminary means and reliabilities (Cronbach alpha) for each item subset (N=284).

Item subset	N° of items	Scale mean	Cornbach alpha	N° of items (reduced scale)	Scale mean	Cronbach alpha with items deleted.
SINGLE	11	3.10	0.45	7	3.25	0.54
INTEG	8	2.64	0.34	4	2.74	0.52
AMBIG	5	2.92	0.45	5	2.92	0.45
CERT	6	3.14	0.20	3	3.18	0.51
CRIT	6	2.26	0.42	4	2.05	0.46
DEPEND	6	2.97	0.00	--	--	--
LEARN	5	2.25	0.47	4	2.32	0.49
WORK	4	2.24	0.41	4	2.24	0.41
INNATE	4	2.52	0.35	3	2.36	0.42
QUICK	5	2.27	0.34	4	2.33	0.38
FIRST	3	2.22	0.25	2	2.06	0.32
EFFORT	2	2.49	-0.10	--	--	--

NB: It was not possible to produce an acceptable scale for the subsets DEPEND and EFFORT

4.6.3 Congeneric modelling

The advantage of a congeneric modelling technique is that the contribution of each observed indicator to the composite scale is weighted to represent differences in its degree of contribution to the latent variable. The computer software, AMOS 3.6 (Arbuckle, 1994), uses a modelling technique called *analysis of moment structures* (or analysis of covariance structures). The process involves fitting a one-factor congeneric measurement model (Jöreskog, 1971) to the observed variables (item scores) for each of the 12 item subsets, which are the latent variables. Items that reduce the reliability of the scale are deleted or given a lower weighting. The goodness-of-fit statistic for a congeneric model amounts to a test of validity because all the variables must represent a single trait.Congeneric modelling, a component of Structural Equation Modelling (SEM), is applied to confirm the validity of an hypothesised model rather than to ‘discover’ a model. Hence, the hypothesised model must be theory-based. This technique is applied appropriately in this instance because Schommer developed the 12 item subsets from a particular theoretical perspective (Schommer, 1990, 1993).

A composite scale reliability was determined for each item subset using the Composite Reliability for Congeneric Measures Model (CRCMM)(Raykov, 1997), since Cronbach's alpha underestimates the reliability of congeneric measures. The data is presented in Table 4.31. The parameters provided as evidence of the soundness and 'fit' of each model are chi-square per degree of freedom (CMIN/DF), Probability level (P), Incremental fit index (IFI) – a type 2 fit index, and Comparative goodness-of-fit index (CFI) – a type 3 fit index. (Hu & Bentler, 1995). The CMIN/DF tests lack of fit resulting from over-identifying restrictions placed on the model and should be low (<2.0). The probability level ranges from 0 to 1, where 1 is a perfect fit. The CFI and IFI vary between 0 and 1, (or approx 1 for the IFI) where 1 is a perfect model fit. The minimum accepted value for overall fit indices (CFI and IFI) is 0.90 (Hoyle & Panter, 1995).

A model was produced for 10 item subsets. See Table 4.31. No model could be produced for *Concentrated effort is a waste of time* (EFFORT) and *Depend on authority* (DEPEND). EFFORT was deleted from the second order factor analysis. DEPEND was retained in view of the acceptable internal consistency of the scale. The 11 item-subsets were then subjected to confirmatory factor analysis as before. The factor structure, with loadings less than 0.4 omitted, is shown in Table 4.32. This is similar to the factor structure that was obtained with the original 12 item-subsets with the exception that CRIT (Don't criticise authority) has taken the place of DEPEND (Depend on authority) as the strongest loading item subset on the fourth factor.

Table 4.31. Summary of models resulting from congeneric structural modelling using AMOS

Subset model	**Retained Items**	**Composite Scale Reliability**	**CMIN/ DF**	**P**	**IFI (Type2 index)**	**CFI (Type3 index)**	**Notes**
Avoid ambiguity (AMBIG)	1, 2, 3, 4, 5	0.92	0.646	0.665	1.026	1.000	Reasonable model. Good reliability.
Success not related to hard work (WORK)	1, 2, 3, 4	0.88	0.157	0.855	1.040	1.000	Good model. Good reliability.
Seek single answers (SINGLE)	1, 2, 3, 4, 6, 8, 10, 11	0.83	0.822	0.689	1.039	1.000	Reasonable model. Good reliability.
Don't criticise authority (CRIT)	1, 4, 5, 6	0.75	0.179	0.836	1.001	1.000	Good model with acceptable reliability.
Avoid integration (INTEG)	3, 5, 6, 8	0.72	0.075	0.928	1.025	1.000	Good model with acceptable reliability.
Ability to learn is innate (INNATE)	1, 2, 3	0.68	0.047	0.829	1.001	1.000	Constrained items 1 & 2. Good model with acceptable reliability.
Learning is quick (QUICK)	1, 2, 3, 4	0.86	1.091	0.351	0.991	0.990	Acceptable model. Good reliability.
Can't learn how to learn (LEARN)	1, 2, 4, 5	0.82	3.72	0.024	0.998	0.998	Weaker model but good reliability. Two items dominate.
Knowledge is certain (CERT)	2, 3, 5	0.58	0.151	0.697	1.000	1.000	Constrained items 2 & 3. An acceptable model but low reliability.
Learn the first time (FIRST)	1, 2, 3	0.77	4.554	0.011	0.658	0.640	All three items constrained. Weak model.
Depend on authority (DEPEND)	1, 3, 4	0.71	0.655	0.519	-3.709	Not computed	Poor model – even with constraints.
Concentrated effort is a waste of time (EFFORT)	---	---	---	---			No model possible Reliability is too low to include the subset.

The four factors identified here, based on the strongest loading item subsets are:

- Factor 1: Belief in Simple Knowledge
- Factor 2: Belief in Fixed Ability
- Factor 3: Belief in Certain Knowledge
- Factor 4: Belief in Omniscient Authority

The fourth dimension, belief in Omniscient Authority, is proposed because of the high loading of CRIT on the fourth factor and because belief in Quick Learning still did not emerge as a clear factor. The two item subsets hypothesised for Quick Learning are QUICK and FIRST but these subsets do not load as predicted – nor as found in Schommer's work. In addition, Factor 4 had DEPEND (zero reliability) as its strongest contributing subset in the first structure produced whereas DEPEND is now a lesser contributor to Factor 1.

Table 4.32. Factor structure emerging from this study following congeneric modelling of 11 item subset scales, loadings > 0.4 (N=284). The factors are sorted to enable easier comparison with Table 2.10.

Subset dimension	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Success is unrelated to hard work		.71		
Learning is quick	.43	.46		
Ability to learn is innate		.56	.46	
Learn first time		.70		
Can't learn how to learn		.62		
Avoid integration	.63			
Don't criticize authority				.86
Seek single answers	.78			
Avoid ambiguity	.73			
Knowledge is certain			.87	
Depend on authority	.63			

In both structures, the item subsets for Quick Learning and Innate Ability tend to merge. Similar, but less strong links are evident in the factor structures derived by Schommer and Dunnell (1997) and Schommer, Crouse and Rhodes (1992). This association may reflect a strong belief within this population that 'quick learning' is associated with 'innate ability' i.e. an individual born with high intellectual ability will also learn things quickly and an individual born with limited ability will not learn things quickly. This is not ‘quick learning’ as hypothesised by Schommer, who intended the interpretation to be ‘learning is quick *or not at all*’ regardless of perceived ability. It could be that physics and engineering students perceive learning in their disciplines to be related to innate ability more than students in other disciplines and hence these two belief dimensions are indistinguishable. There is some supporting evidence from interviews in which students expressed the following views about the difficulties of learning physics:

- Students are limited in learning physics by ‘ability’ or ‘capacity’.
- Students can improve ‘mathematical ability’ but not ‘physics ability’.
- Physics is difficult because there are only few ways to explain basic concepts. If students can’t understand at this point, they never will.
- Initially, students expect to learn but not necessarily understand. Understanding is a bonus.

Comparison with other reported factor structures

There are similarities between this factor structure and those reported previously in Tables 2.9 to 2.11. The first two factors emerged clearly, as has been the case in previous studies, although the order of the first two is reversed. This reversal was also reported in Schommer’s adult population. A more important difference is that the factors are not dependent on items subsets with low reliability scales. The third and fourth factors are still problematic and may be dependent on the nature of the particular population under study. The highest loading subset for Factor 3 is CERT, which is not a strong model. Factor 4, clearly dependent on CRIT, is not supported by its other hypothesised subset, DEPEND.

4.6.4 Discussion

Since beliefs undergo change over high school and college years, some differences might be expected. Adults are less emphatic in their beliefs about authority figures, possibly because of life experience. Authority figures are more likely to be the peers of adults – equals rather than people or institutions to be revered. It is also possible that some beliefs are weaker than others. Weakly held beliefs, whether they are naïve or constructivist, may not be manifested as readily or consistently as strongly held ones. The concept of differentiating between weakly or strongly held beliefs, or core or peripheral beliefs, is not specifically addressed in other studies using the QEB. The exception is Brownlee, Purdie and Boulton-Lewis (2001) who have not, however, used QEB data in ways that are comparable with this study.

Three issues, however, still remained unresolved:

1. The discrepancies between this factor structure and those of Schommer and others may be explained by differences in populations under study. However, the lack of consistent correspondence between the factor loading of item subsets and Schommer's hypothesised dimensions may also indicate an inability of either the QEB, or its theoretical underpinnings, to adequately represent belief dimensions.
2. The correspondence between my initial factor structure and the structure resulting after the modification of the scales using congeneric modelling may not necessarily indicate a strength of the second procedure. The weighting of items to produce the modified scales can vary considerably. When a further weighting is applied in the form of factor score weights to produce scores on the four belief factors, the effect may be excessive weighting of a few items and/or negation of the weighting of others.
3. Despite the approximate replication of factor structures in all studies, there remains sufficient uncertainty in this structure to be confident in proceeding. A four-factor solution is favoured, but the third and fourth factors identified thus far appear tenuous.

These issues crystallised when the high-loading items for each factor were reviewed. There appeared to be little relationship between some items and their expected or hypothesised factor loading. A possible explanation is that Australian students are interpreting and answering some items differently from those in Schommer's work. As a result, the following assertions or hypotheses were generated and underpin the remaining procedure followed:

1. Students' epistemological beliefs are multidimensional – three, four or five dimensions appear plausible.

2. Forcing items to load as hypothesised by grouping items into subsets, albeit based on substantive theory, masks some information about student beliefs.
3. Students interpret and respond to some QEB items differently than anticipated.

4.7 Re-analysis of QEB data

The original data was subjected to a ‘first-order’ factor analysis of all 63 items. Three, four and five factor solutions were investigated but a four-factor solution was the most plausible. There were fewer high-loading, negative items and the structure was the most interpretable one, based on the nature of the highest loading items. All items loading less than 0.3 on any factor were removed, leaving 44 items, and a further factor analysis conducted. A final solution is shown in Table 4.33. The four-factor solution has rotation sums of squared loadings for the four factors exceeding 2.0, accounting for 28.5% of variance.

- KMO measure of sampling adequacy = 0.710
- Bartlett’s test of sphericity: Chi-square = 2594, df = 946, sig = 0.000.

The KMO (Kaiser-Meyer-Olkin) measure of sampling adequacy should be greater than 0.6 for factor analysis to proceed. Bartlett’s test of sphericity tests the null hypothesis that the population correlation matrix is an identity matrix. In this case, the null hypothesis is rejected ($p<0.000$) and the correlation matrix is suitable for factor analysis.

To help identify the nature of the four factors, I used Schommer’s original five dimensions and how students might exhibit beliefs that fitted these dimensions. I then added a number of other descriptors that I believe could also represent or illustrate such beliefs. See Table 4.34. Some of these descriptors were drawn from the interview data.

Table 4.33. Loading of 44 items of the QEB onto four factors (N=284).

Item	Factor 1	Factor 2	Factor 3	Factor 4
QUICK3	.631			
FIRST2	.604			
LEARN2	.583			
LEARN4	.497			
WORK1	.483			
WORK3	.456			
LEARN3	.445			
LEARN1	.437			
INTEG7	.415			
CRIT1	.412			
SINGL10	-.396	.375		
SINGL7	.381			
EFFRT2	.372			
QUICK5	.311			
INNAT3	.308			
AMBIG3		.632		
INTEG8		.624		
AMBIG5		.600		
CRIT4		.513		
QUICK4		.512		
DEPEN1		.440		
EFFRT1		.435		
INTEG6	-.352	.432		
SINGL4		.406		
SINGL1		.398		
SINGL3	-.331	.389		
QUICK1		.347		
SINGL11		.341		
FIRST1	.319	.333		
SINGL2		.322		
CERT2			.743	
CERT3			.712	
INNAT1			.456	
INTEG3		.333	.435	
INNAT2		.302	.371	
DEPEN4			.341	
CRIT6	.303			.595
AMBIG2				.498
CRIT5	.342			.439
SINGL6				.388
INTEG1				.351
SINGL8				.340
CERT1				.339
CRIT3				.330

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 9 iterations.

Table 4.34. Alternative descriptors representing students' epistemological beliefs in five belief dimensions.

Belief dimension	**Item subset**	**Alternative belief descriptors (stated in the naïve form). Those in italics are drawn from student interview data.**
Simple Knowledge	Seek single answers Avoid integration	Difficult problems or ideas should be simplified *Different (physics) topics or concepts are unrelated* *Avoid complication or unnecessary ideas or facts* Complicated ideas are not for students Learning involves discrete facts Learning does not necessarily include understanding Problems have a single solution
Certain Knowledge	Avoid ambiguity Knowledge is certain	There exists a truth independent of people Discovering truth is an ultimate goal Physics/science is about known facts *Right answers exist for all problems* *Seeking the right answer is important* Ambiguity can be resolved Experts are privy to truth
Omniscient Authority	Don't criticize authority Depend on authority	*It is the job of teachers to impart knowledge* If students don't learn, teachers are at fault *Authority figures know the answers* *Scientists are authority figures* *Science/physics has authority* Scientific activity is not to be criticised There is no sense in challenging authority
Innate Ability	Can't learn how to learn Success is unrelated to hard work Ability to learn is innate	IQ or intelligence is inherited IQ or intelligence determines achievement or potential to learn *Working hard won't help if you don't have 'the ability'* Ability to learn cannot be changed
Quick Learning	Learning is quick Learn first time Concentrated effort is a waste of time	All learning is fast Don't waste too much time trying to learn difficult ideas Give up if you don't understand immediately Clever people are fast learners Understanding is immediate

I then classified the items according to this new scheme, to compare them with Schommer's original theoretical model. See Table 4.35, columns 4 and 5. Most reclassified items confirmed Schommer's classification, but some (e.g.3, 21, 27, 44, 54) explained more adequately the different observed loadings.

The four factors thus identified, based on the character of items and students' most probable interpretation of the highest loading items are:

Factor 1: Belief in Fixed Ability/Quick Learning (ranging from ability to learn/learn quickly is fixed at birth to the ability to learn/learn quickly can be changed).

Factor 2: Belief in Simple Knowledge (ranging from knowledge is unambiguous, isolated bits of information to knowledge consists of highly interrelated concepts).

Factor 3: Belief in Certain Knowledge (ranging from knowledge is absolute and unchanging to knowledge is relative and evolving).

Factor 4: Belief in Expert Authority (ranging from experts know the truth and deliver knowledge to knowledge is developed by individuals).

After reviewing the highest loading factors and in view of physics students' statements about authority in physics, I re-defined the fourth factor from Belief in Omniscient Authority to Belief in Expert Authority.

Table 4.35. Highest loading items for each of four factors. Schommer's and alternative classification of items. S = Simple Knowledge, C = Certain Knowledge, O = Omniscient Authority, I = Innate Ability, Q = Quick Learning. Column 1 is the number of the item in the QEB. Column 2 is an identifier code for each item.

			Schommer's item classification (see note)	**Possible alternative classification (see note)**
FACTOR 1: Belief in Fixed Ability				
39	Quick3	If a person can't understand something within a short amount of time, they should keep on trying.	Q	Q
24	First2	If I find the time to re-read a textbook chapter, I get a lot more out of it the second time.	Q	Q
15	Learn2	The most successful people have discovered how to improve their ability to learn.	I	I
28	Learn4	Everyone needs to learn how to learn.	I	I
26	Work1	Genius is 10% ability and 90% hard work.	I	I
25	Learn3	Students have a lot of control over how much they can get out of a textbook	I	I
43	Work3	Getting ahead takes a lot of work.	I	I
4	Learn1	A course in study skills would probably be valuable.	I	I
3	Crit1	For success in school, it's best not to ask too many questions.	O	S / Q
54	Integ7	A really good way to understand a textbook is to re-organise the information according to your own personal scheme	S	Q / S
53	Effort2	Usually you can figure out difficult concepts if you eliminate all outside distractions and really concentrate.	Q	Q
30	Singl7	A sentence has little meaning unless you know the situation in which it is spoken.	S	S
20	First1	Going over and over a difficult textbook chapter usually won't help you understand it.	Q	Q
55	Innate3	Students who are "average" in school will remain "average" for the rest of their lives.	I	I
60	Quick5	Learning is a slow process of building up knowledge.	Q	Q
FACTOR 2: Belief in Simple Knowledge				
41	Ambig3	If professors would stick more to the facts and do less theorising, one could get more out of university lectures.	C	S
63	Integ8	You will just get confused if you try to integrate new ideas in a textbook with knowledge you already have about a topi	S	S
44	Ambig5	It's a waste of time to work on problems which have no possibility of coming out with a clear-cut and unambiguous answer	C	C / S
13	Crit4	People who challenge authority are over-confident.	O	O
50	Quick4	Working hard on a difficult problem for an extended period of time only pays off for really smart students.	Q	Q

5	Depend1	How much a person gets out of school mostly depends on the quality of the teacher.	O	O / I
19	Singl4	Educators should know by now which is the best method, lectures or small group discussions.	S	S
11	Singl1	A good teacher's job is to keep his students from wandering off the right track.	S	S
38	Integ6	When I study, I look for the specific facts.	S	S
58	Singl10	I really appreciate instructors who organise their lectures meticulously and then stick to their plan.	S	S
51	Effort1	If a person tries too hard to understand a problem, they will most likely just end up being confused.	Q	S / Q
17	Singl3	The most important aspect of scientific work is precise measurement and careful work.	S	S
59	Singl11	The best thing about science courses is that most problems have only one right answer.	S	S / C
1	Quick1	If you are ever going to be able to understand something, it will make sense to you the first time you hear it.	Q	S / Q
16	Singl2	Things are simpler than most professors would have you believe.	S	S

FACTOR 3: Belief in Certain Knowledge

12	Cert2	If scientists try hard enough, they can find the truth to almost anything.	C	C
21	Cert3	Scientists can ultimately get to the truth.	C	C
31	Integ3	Being a good student generally involves memorising facts.	S	C / S
8	Innate1	The ability to learn is established at birth.	I	I
47	Innate2	Some people are born good learners, others are just stuck with limited ability.	I	I
40	Depend4	Sometimes you just have to accept answers from a teacher even though you don't understand them.	O	C / O

FACTOR 4: Belief in Expert Authority

46	Crit6	Often, even advice from experts should be questioned.	O	O
27	Ambig2	I find it refreshing to think about issues that authorities can't agree on.	C	O / C
45	Crit5	You should evaluate the accuracy of information in a textbook, if you are familiar with the topic.	O	O
7	Crit3	I often wonder how much my teachers really know.	O	O
33	Singl8	Most words have one clear meaning.	S	S / O
14	Integ1	I try my best to combine information across chapters or even across classes.	S	S
23	Singl6	The most important part of scientific work is original thinking.	S	O / S
2	Cert1	The only thing that is certain is uncertainty itself.	C	C

ITEMS DELETED FROM FACTOR ANALYSIS

6	Crit2	You *can* believe almost everything you read.	O	O
9	Ambig1	It is annoying to listen to a lecturer who cannot seem to make up his mind as to what he really believes.	C	O / S
10	Quick2	Successful students understand things quickly.	Q	Q / I
18	Integ2	To me studying means getting the big ideas from the text, rather than details.	S	S
22	Singl5	You never know what a book means unless you know the intent of the author.	S	S
29	Depend2	When you first encounter a difficult concept in a textbook, it's best to work it out on your own.	O	O
32	Work2	Wisdom is not knowing the answers, but knowing how to find the answers.	I	C
34	Cert4	Truth is unchanging.	O	C
35	Integ4	If a person forgot details, and yet was able to come up with new ideas from a text, I would think they were bright.	S	S
36	Depend3	Whenever I encounter a difficult problem in life, I consult with my parents.	O	O
37	Integ5	Learning definitions word-for-word is often necessary to do well on tests.	S	S
42	Ambig4	I don't like movies that don't have an ending.	C	C / S
48	Cert5	Nothing is certain, but death and taxes.	C	C
49	Work4	The really smart students don't have to work hard to do well in school.	I	I
52	First3	Almost all the information you can learn from a textbook you will get during the first reading.	Q	S / Q
56	Singl9	A tidy mind is an empty mind.	S	S
57	Innate4	An expert is someone who has a special gift in some area.	I	I
61	Cert6	Today's facts may be tomorrow's fiction.	C	C
62	Learn5	Self-help books are not much help.	I	I

Note: S = Simple Knowledge, C = Certain Knowledge, O = Omniscient Authority, I = Innate Ability, Q = Quick Learning

4.7.1 Internal consistency of scales

Estimates of the internal consistency of the four scales, calculated as Cronbach's alpha and using items loading greater than 0.3, are shown in Table 4.36. Cronbach's alpha was 0.787 for all 44 items. There is no published data with which to compare this. Windschitl and/ Andre (1998) reported 0.69 using the average of the 12 item subsets. My data produced 0.59 using the average of 11 item subsets following congeneric modelling.

Evidence for the independence of the four factors is provided by the correlation between each factor. A low correlation coefficient indicates that the factors are independent dimensions. In this study there is a low but significant negative correlation ($r = -0.155$, $p<0.01$) between the first and fourth factors. This suggests that some students who believe naively in Fixed Ability/Quick Learning also tend to believe that knowledge is developed by learners rather than provided by authoritative experts, however the correlation is small enough to be ignored.

Table 4.36. Estimate of scale reliabilities and correlations with other scales for four factors following factor analysis of 44 items of the QEB (N=284).

Factor	Number of items loading >0.3	Cronbach alpha	Pearson correlation coefficient, r.
Fixed Ability/Quick Learning(FA/QL)	20	0.64[a]	SK: -0.022 CK: 0.021 EA: -0.155**
Simple Knowledge (SK)	20	0.76	CK: 0.000 EA: -0.037
Certain Knowledge (CK)	6	0.58	EA: -0.031
Expert Authority (EA)	8	0.46[b]	

[a] Without the three negatively loading items, r = 0.75
[b] Deletion of item CERT1 would improve this marginally.
** p<0.01 (2-tailed)

Freeing the items to load onto factors independently of one another has produced a stronger and more explainable factor structure. For example, in the previous subset structure, the two items contributing to EFFORT effectively counteracted one another and took their information about student beliefs out of the analysis. By allowing the items to enter the analysis independently, both load onto different factors, suggesting that they are tapping into different aspects of students' beliefs.

These four factors, although associated with some uncertainty, were now considered appropriate for further use in this study. Weakness of the third and fourth factors, Certain Knowledge and Expert Authority, is acknowledged. The whole construct of epistemological belief dimensions and their measurement, however, is tentative and evolving, and as such, some ambivalence must be accepted. However, the issues raised above are worthy of further investigation if theories related to the dimensionality of epistemological beliefs are to be advanced.

4.8 Discussion – Chapter 4

The purpose of this discussion is to bring together the results of this chapter and to draw out overall trends or themes that have emerged. The analysis has used simple comparative and correlational statistics, coupled with an interpretive approach in which participant observation has been a key aspect of interpreting the data.

I will also relate these results to the learning model that was proposed in Chapter 1 and reprinted below.

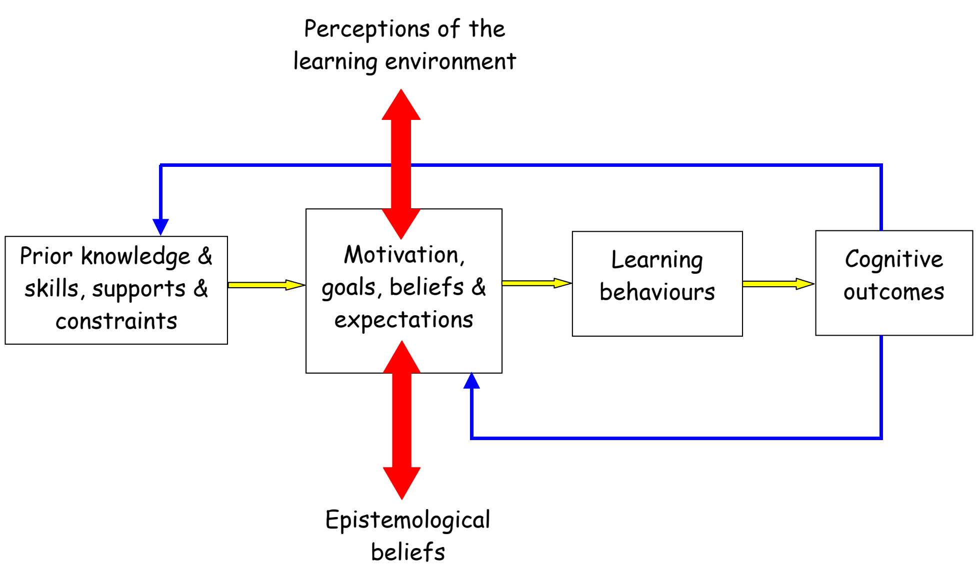

Figure 4.3. In this study, it is assumed that epistemological beliefs and students' perception of their learning environment affect their learning behaviour and thus will impact on cognitive outcomes. The results of student learning hence change their knowledge and beliefs.

For all students taken together, there is a clear link between beliefs about the *structure* of knowledge, i.e. beliefs in Simple Knowledge and Certain Knowledge, and cognitive outcomes, through their learning behaviours. In general, naïve belief in Simple Knowledge and Certain Knowledge are associated with the use of a narrow range of traditional learning strategies and lower cognitive outcomes. More sophisticated epistemological beliefs are associated with a wider range of learning strategies and higher cognitive outcomes. If the model is an appropriate representation, then the links may be thought of as causal. Naïve beliefs result in students restricting their learning activities to a narrow range such as those which are modelled in class or which commonly appear in tests or exams, but which, in general lead to lower cognitive outcomes. Students holding more sophisticated beliefs choose a wider variety of activities for learning which, in general, lead to higher cognitive outcomes.

The following figure (4.4) represents these very broad general relationships:

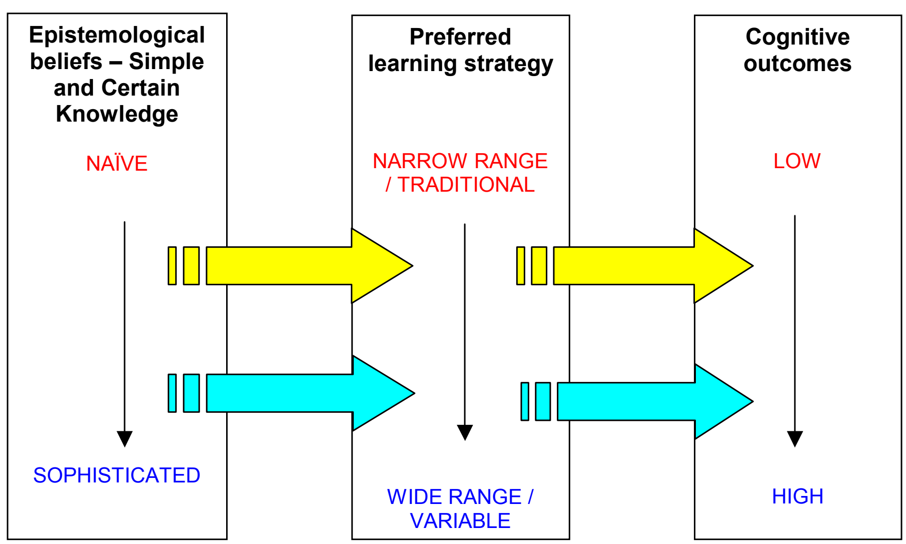

Figure 4.4. The diagram shows that, in general, naïve belief in Simple/Certain Knowledge leads to use of a narrow range of traditional learning strategies and lower cognitive outcomes. More sophisticated epistemological beliefs lead to use of a wider range of learning strategies and higher cognitive outcomes.

What are the differences between SI and TI students? SI students, overall, hold more sophisticated beliefs in Simple Knowledge and Certain Knowledge. Overall, they choose a wider range of learning strategies, and overall, they have better cognitive outcomes, especially with respect to conceptual understanding.

Students' responses to their learning environment are related to their beliefs about the speed and ease of knowledge development, i.e. their beliefs about learning, rather than their beliefs about the structure of knowledge. Students with more sophisticated beliefs tend to rate the constructivist learning environment more highly than those with more naïve beliefs. SI students with more naïve beliefs in Expert Authority rate some aspects of the learning environment, in particular, Leadership, more highly than those with more sophisticated beliefs. The same effect is not noted for TI students. It thus appears that there is a proportion of SI students who want to be directed or given more explicit help in their learning. They want the control of their learning to remain vested in their teachers rather than in themselves. Further evidence for this provided by the Teacher Interpersonal Qualities aspect of the learning environment data. Students see teacher behaviour as more important than their own behaviour.

SI students rate their learning environment more highly constructivist than do TI students, and also express a greater degree of satisfaction with their learning environment. SI students with lower cognitive outcomes, however, tend to rate the Teacher Interpersonal Qualities of the learning environment more highly than do students with higher cognitive outcomes.

4.9 Review of Chapter 4

In this chapter I have presented the data collected throughout the period of the study, together with an analysis and conclusions drawn from the analysis. These conclusions are situated throughout, and at the end of, Part B.

In the next Chapter, I use multidimensional scaling to represent key variables and relationships explored individually in this chapter, on learning environment maps.

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Note: Viewing Figures

For best results figures should be viewed at 300% online or printed and viewed off line.

CHAPTER 5: COMPARISON OF LEARNING ENVIRONMENTS - CORRELATIONAL STUDY

Multidimensional scaling (MDS) rests on the premise that a picture is worth a thousand numbers.

(Young, 1987, p. 3)

5.1 Introduction

Thus far I have treated students' learning preferences, epistemological beliefs and perceptions of their learning environment as three separate and ostensibly unrelated phenomena. An overarching aim, however, has been a systemic study of the Studio learning environment using a methodological technique suggested by Salomon (1996) in his study of a technology-intensive learning environment. This involves investigating structural patterns of relationships among variables that constitute the Studio learning environment. The patterns are represented in maps or configurations produced by multidimensional scaling of data. Thus, in this part of the study I am investigating efficacy of representing the complex data and interrelationships that represent the different learning environments in a simpler, more visual form.

5.1.1 Specific research questions

The relevant research questions (with original numbers as used in Chapter 1) addressed in this section are:

2. What roles do Studio students' perceptions of their learning environment play in their physics learning?
    a. What are Studio students' perceptions of their *Actual* and *Preferred* learning environment, and how are they different from those of students in the traditional course?
    b. Are Studio students' perceptions of their learning environment related to their physics learning outcomes?
3. What roles do Studio students' epistemological beliefs play in their physics learning?

a. Are students' epistemological beliefs related to their physics learning outcomes?
b. Are students' epistemological beliefs related to their perceptions of the learning environment?

4. Can multidimensional scaling techniques be used to represent and differentiate between the Studio and Traditional learning environments?

5.2 Data processing

The relevant correlational matrices (direct printouts from SPSS-10) are included in Appendix 2.2.3.

Figures 5.1A and 5.1B show Stress and RSQ versus dimensionality (R) for Series I and Series II solutions. These terms were explained in Section 3.3.3. The most favoured solutions were those with Stress less than 0.1 and RSQ greater than 0.90. After considering the data, I decided to use three-dimensional solutions, but for ease of interpretation, I have represented each solution in a two-dimensional MAP using the two dimensions with greatest spread projected onto the third dimension.

The maps (Figures 5.6 – 5.21) were drawn using Microsoft Excel. All maps have been replicated to the same scale. Several maps were reflected about the y-axis and several were rotated through 30-60° to give them at least a basic pattern correspondence to aid visual interpretation. (Remember that patterns can be translated, rotated, reflected or rescaled without altering the solutions. See Section 3.3.5).

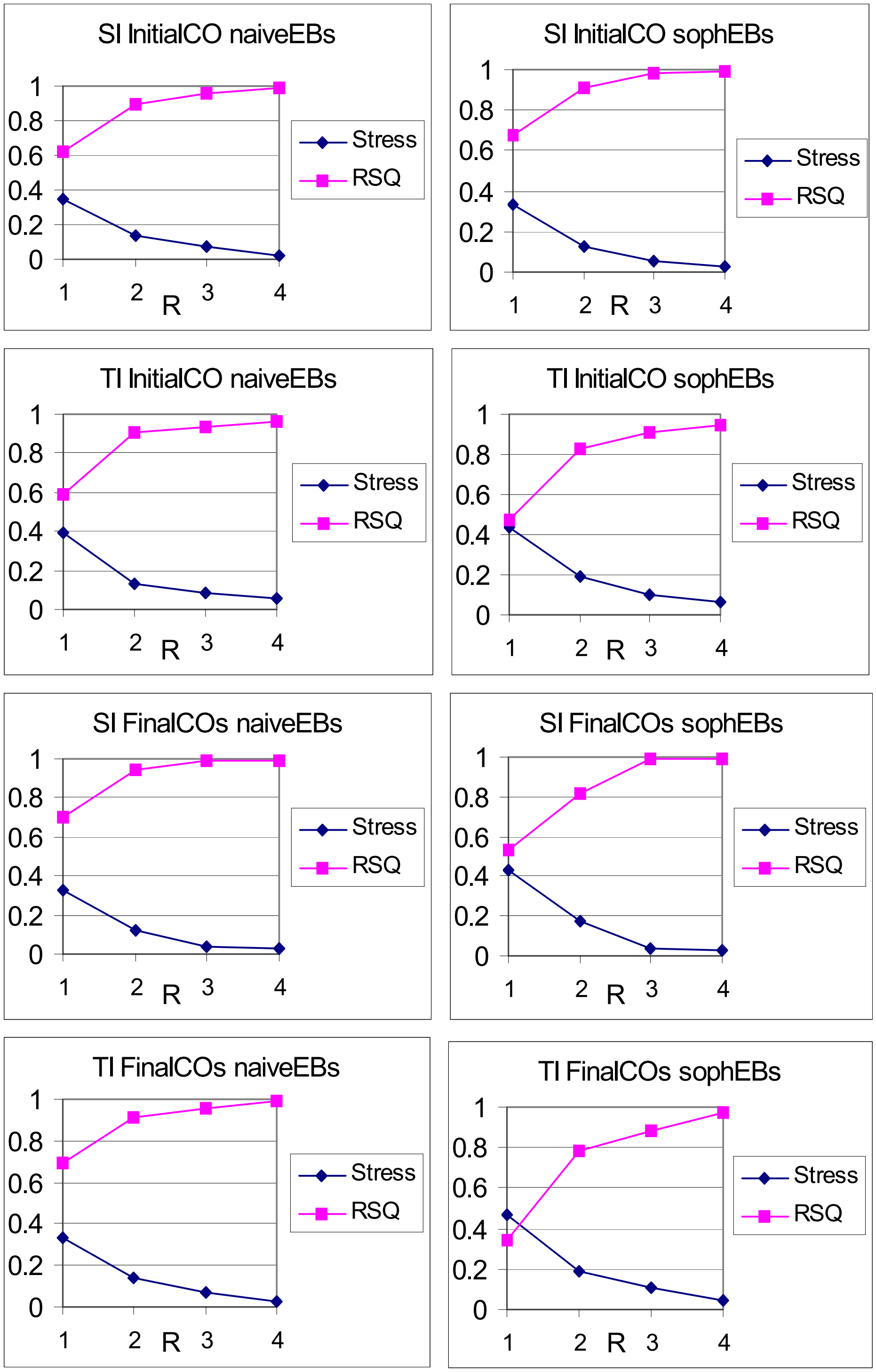

Figure 5.1A. Plots showing dimensionality (R) versus stress and RSQ for Map Series I MDS solutions (CO/EB/IT). Three-dimensional solutions were chosen in each case.

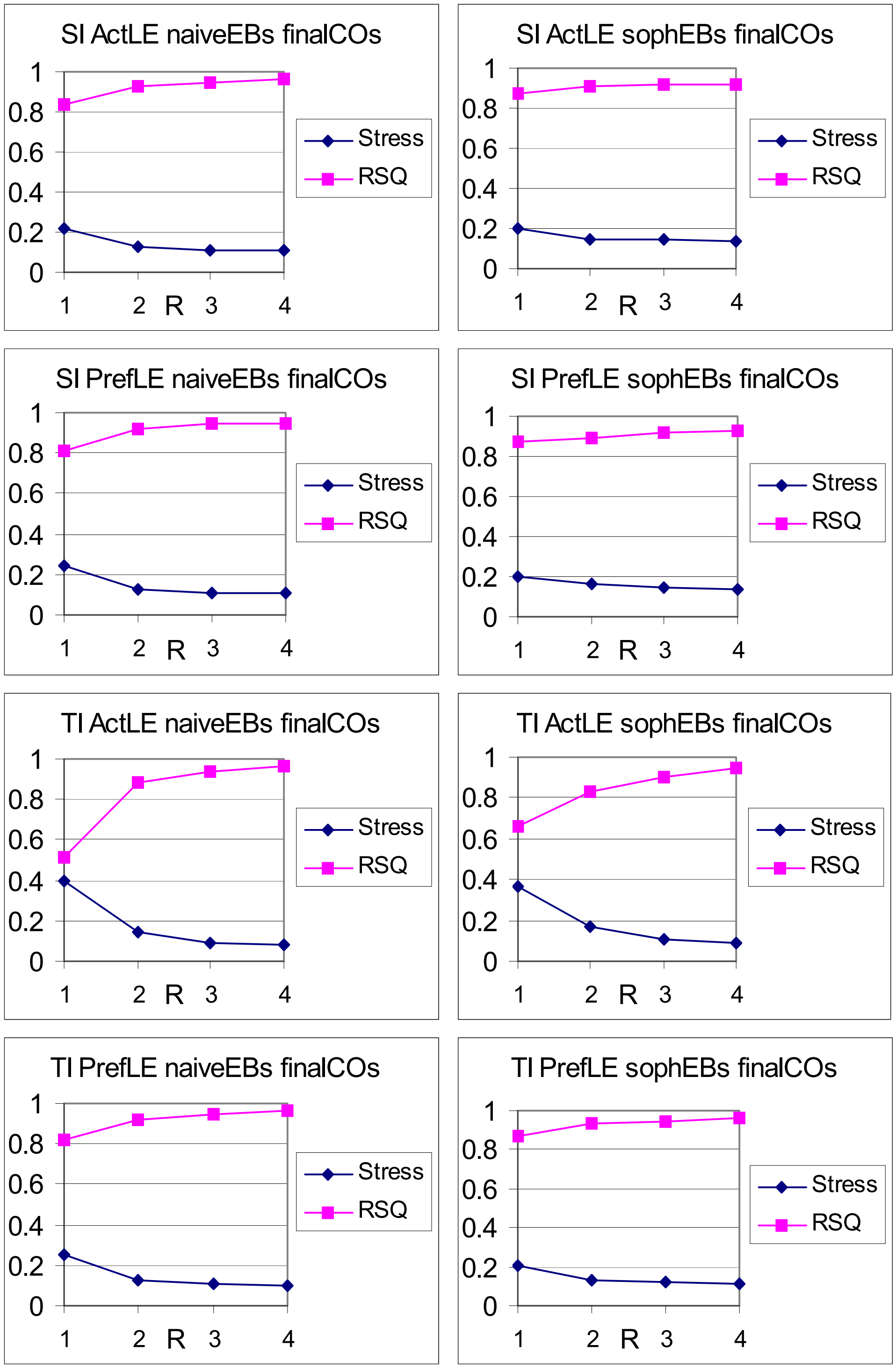

Figure 5.1B. Plots showing dimensionality versus stress and RSQ for Map Series II MDS solutions (CO/EB/LE). Three-dimensional solutions were chosen in each case.

5.3 Description of maps

The maps (patterns) outlined below will be reproduced and analysed in Section 5.6. **Two maps will be provided for each set of parameters**; one showing the nature and strength of the correlations in the raw data (the 'A' map) and one showing regions or groupings of variables that have interpretive meaning (the 'B' map). A summary of the parameters used in the construction of each map is shown in Figure 5.2.

5.3.1 Overview of <u>Map Series I</u>: Cognitive outcomes, epistemological beliefs and IT self-efficacy beliefs (CO/EB/IT) maps

SI and TI students on course entry (Maps 1-4)

These are patterns representing SI and TI students respectively as they enter the course. The term 'cognitive status' is being used to denote the results of students on relevant tests prior to beginning university study. Cognitive status variables portrayed will be TEE physics examination score (TEE PHYS), the tertiary entrance rank (TER) – both of which were equal for the matched SI and TI groups – and the FMCE pretest score that students completed in the first week of semester 1. Epistemological beliefs (EBs) are the initial scores based on data collected in the first week of the year. Two other variables are initial IT self-efficacy beliefs - IT Skill (students' perceptions of their competence in using IT) and IT Confidence (how they feel toward the use of IT in learning).

SI and TI on course exit (Maps 5-8)

These are patterns representing SI and TI students respectively as they leave their first year subjects. The cognitive outcome variables portrayed will be the mid-year examination score (EXAM), quantum mechanics test score (QM Test) and FMCE posttest score. Although referred to as 'on course exit' cognitive outcomes, these are three assessments conducted at different times during the year. Epistemological beliefs (EB) are the final measures based on data collected at the end of the year. IT self-efficacy beliefs are final IT Skill and final IT Confidence.

The purpose of the Map Series I is to explore *systemic* change in the SI group over a year. The TI maps are included to give comparative meaning to the SI maps.

5.3.2 Overview of Map Series II: cognitive outcomes, epistemological beliefs, IT self-efficacy beliefs and learning environment (CO/EB/LE) maps

These are patterns representing students' epistemological beliefs, cognitive outcomes, perceptions of the learning environment and IT self-efficacy beliefs soon after the start of semester 2. The cognitive outcome variables portrayed will be the mid-year examination score (EXAM), quantum mechanics test score (QM Test) and FMCE posttest score. Epistemological beliefs and IT beliefs are the 'final' scores. The learning environment perceptions portrayed are both *Actual* and *Preferred* learning environment assessments.

SI and TI students' perceptions of their *Actual* learning environment (Maps 9-12)

The learning environment perceptions represented in these maps are students' scores on the six *Actual* USCLES scales, with the first three (Student Communication and Reflection) shown differently from the second three (Teacher Interpersonal Qualities). See Figure 6.5 for map legend and colour codes. The cognitive outcome variables portrayed will be the mid-year examination score (EXAM), quantum mechanics test score (QM Test) and FMCE posttest score. Epistemological beliefs (EB) are the final scores based on data collected at the end of the year. IT self-efficacy beliefs are final IT Skill and final IT Confidence.

SI and TI students' perceptions of their *Preferred* learning environment (Maps 13-16)

The learning environment perceptions represented in these maps are students' scores on the six *Preferred* USCLES scales, with the first three (Student Communication and Reflection) shown differently from the second three (Teacher Interpersonal Qualities). The cognitive outcome variables portrayed will be the mid-year examination score (EXAM), quantum mechanics test score (QM Test) and FMCE posttest score.

Epistemological beliefs (EB) are the final measures based on data collected at the end of the year. IT self-efficacy beliefs are final IT Skill and final IT Confidence.

The purpose of Map Series II is to explore systemic/structural differences between:

1. SI and TI students' *Actual* (experienced) learning environments.
2. SI and TI students' *Preferred* learning environments.
3. SI students' *Actual* versus *Preferred* learning environments compared with TI students' *Actual* versus *Preferred* learning environments.

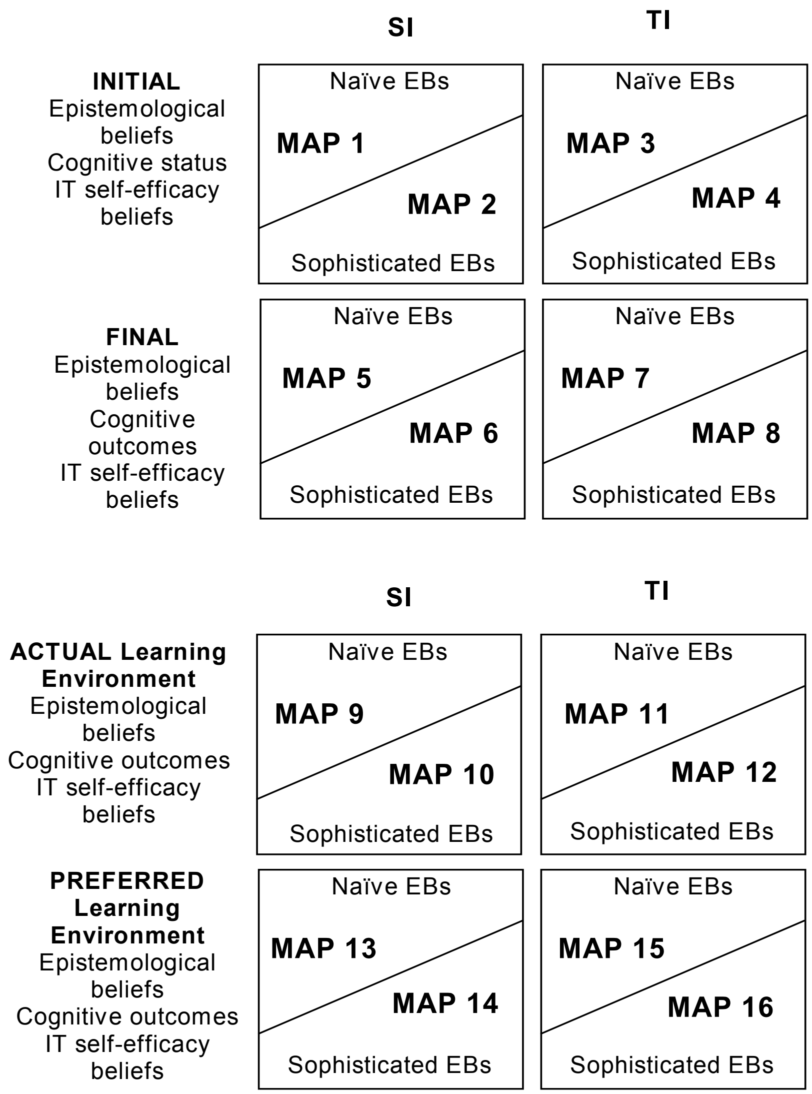

Figure 5.2. Summary of the MDS maps showing parameters used in the construction of each one.

5.3.3 Epistemological beliefs in MDS maps

The use of epistemological beliefs in MDS introduces a unique problem. Unlike most scales that run from a low to a high score, representing a range from a low attribute to a high attribute, epistemological beliefs are measured on a double-ended scale. Epistemological belief scales range from 1 (sophisticated view) to 5 (naïve view). Hence, highly *naïve* is represented as a *high* score and highly *sophisticated* is represented as a *low* score.

I will illustrate the above with the following example: If for a class, scores on an epistemological belief scale are correlated against a cognitive outcome score and a positive correlation results, it means that the more naïve the belief, the higher the cognitive outcome measure, and the more sophisticated the belief, the lower the cognitive outcome measure. If this correlation is represented in a MDS configuration (map) as a 'similarity', the two points (epistemological belief and cognitive outcome) would appear close together. So, if an epistemological belief dimension point is located close to cognitive outcome point, it signifies that students with the more naïve belief tend to have higher cognitive outcomes, and students with more sophisticated belief tend to have lower cognitive outcomes.

If the correlation coefficient between the epistemological belief scores and cognitive outcome scores is made **negative** (i.e. **reversed** in sign), the epistemological belief scale now effectively has highly *sophisticated* as the *high* score and *naïve* as the *low* score. Therefore, in the example above, the point representing the epistemological belief dimension will map far away from the cognitive outcome point. This is, in effect, representative of students with more sophisticated epistemological beliefs.

Thus, it is possible to produce **contrasting maps**, one that is more representative of students who have more *naïve* epistemological beliefs and another representative of students who have more *sophisticated* epistemological beliefs simply by changing the sign of the correlation coefficient between epistemological beliefs scores and all other scores in the correlation matrix. Thus, each of the maps referred to in Sections 5.3.1 and 5.3.2 have contrasting versions, representing students with naïve and sophisticated epistemological beliefs respectively. The maps with **odd numbers** represent students with more naïve beliefs and the maps with **even numbers** represent students with more sophisticated beliefs. Points representing other variables should remain essentially in the same position relative to each other (see below). It should be emphasised that these contrasting maps *must tell the same story*, since they are derived from the same raw data.

Contrasting maps will be used to explore differences between how students with naïve beliefs and students with sophisticated beliefs perceive the same environment. To my knowledge, MDS has not been used in this way before.

Reliability and validity of solutions

The process just described can also provide support (or otherwise) for the reliability and validity of solutions. If correlations between epistemological beliefs and other variables that constitute a particular map are reversed in sign, and a second map produced (now representing sophisticated beliefs as the upper scale limit), the basic pattern formed by all other variables should remain essentially the same. If not, reliability of the solution must be questioned. Similarly, if the two solutions do not *tell the same story* then the validity of the interpretation must be questioned.

5.4 Interpreting MDS maps

5.4.1 Identifying regions

A region on a correlational MDS map marks a group of points whose variables are mutually associated through correlation, i.e. points, X, Y and Z would constitute a region if there were a high degree of mutual correlation among all three.

Only a few reported studies are based on correlational data. See, for example, (Bar-On & Perlberg, 1985; Kruskal & Wish, 1978; Salomon, 1996; Schiffman, Reynolds & Young, 1981). The techniques for identifying regions vary from study to study, depending mostly on the nature of the proximities data and on the variables themselves. The method I will use has been adapted from that described by Kruskal and Wish (1978).

Constructing regions

1. **Solid black lines** are drawn between all points/variables that have a significant, positive correlation ($p<0.05$).

2. **Solid pink lines** are drawn between all variables that have a significant, negative correlation ($p<0.05$).
3. **Dotted black lines** are drawn between all variables that have positive correlations greater than 0.2, but are non-significant.
4. **Dotted pink lines** are drawn between all variables that have negative correlations less than -0.2, but are non-significant.

Nested regions

One region may be constructed around another to include one or more variables that have a lesser degree of mutual correlation between the variables in the inner region and/or among themselves. A lesser degree of correlation might be represented by a significant correlation to one variable in the inner region and positive but non-significant correlations to several others. In this analytic method, therefore, several non-significant correlations may contribute to making meaning of maps whereas in a more conventional analysis, these non-significant correlations might be ignored.

Possibilities for nested structures are shown below in Figure 5.3. The meanings given to such nested regions will be discussed later.

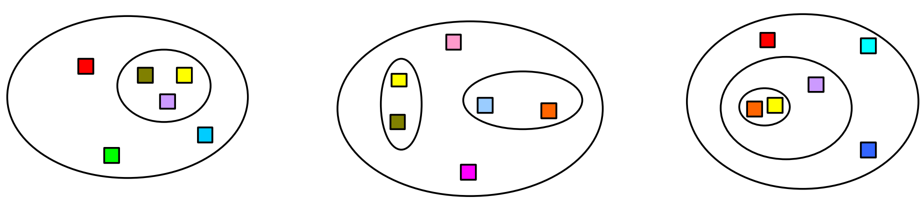

Figure 5.3. Possible configurations of nested regions – showing different degrees of inter-correlation.

Coxon (1982) suggests that other analytical techniques such as cluster analysis may be used to make decisions about the structure of regions. While I found that hierarchical cluster analysis was useful in confirming decisions about the grouping of closely associated variables and in deciding those that are quite separate, I do not think that hierarchical cluster analysis necessarily provides meaningful information about groupings near the middle of a MDS map that incorporates both positive and negative correlations. When using correlations as proximities, the most significant values are the extremes, the large positive or large negative values. Those in the middle, near zero, tend to have less meaning. Cluster analysis, like MDS, gives all values equal significance in grouping or locating points. However, when interpreting MDS configurations, it should only be the significant, or close to significant, correlations that determine groupings. There will usually be points in the centre of an MDS map that may not reliably be grouped. Hence, reference to the original data will be the primary method of deciding regions.

The position of any given point is not unique in that it has its own isotonic space in which it can be positioned anywhere without affecting stress (Coxon, 1982, p. 93). The more points, the smaller this region. Hence one should be wary of extracting too much meaning from the apparent closeness of any two points, particularly in maps with few variables.

Separated regions

Negative correlations are used to distinguish between regions that have nothing in common, or are in some respects 'opposites'. Such regions usually appear on different sides of a MDS map.

Variables that are not consistently or substantially correlated with any other variables generally will appear near the centre of a map and hence may not be included in any region. Salomon referred to such central points in his maps as "variables that appear to constitute the core of the learning environment; everything else revolves around them and relates to them" (Salomon, 1996, p. 373). I do not entirely I agree with this interpretation of centrality. Points (variables) that map near the centre are essentially uncorrelated in any consistent way with all other variables. This does not really constitute "[giving] the learning environment its flavour" (Salomon, 1996, p.373). The points, however, may be central in that they form a bridge or a link between otherwise uncorrelated or negatively correlated variables. What is also important is where these points (variables) were in the initial map and if, and hence why, they migrated to a new position in the final map.

5.4.2 What MDS maps do not show

One must remember that these MDS maps are based on correlations only. Absolute differences between the variables for the two groups – means, variance etc – may exist but will not show up. Taking absolute differences into account will add a further dimension to the analysis of maps.

5.4.3 Dimensionality and size/shape of regions

Dimensionality and 2D versus 3D solutions

As discussed in Chapter 3, MDS solutions can have different dimensionalities. Decisions on the most appropriate number of dimensions is made on goodness-of-fit measures and ease of interpretation of the configuration, and in the case of axial interpretation method, independent assessment of the orientation and meaning of the axes. There appear to be pros and cons for either two-dimensional or three-dimensional solutions, over and above the 'stress vs dimensionality' indications of goodness-of-fit (see Chapter 3).

A regional interpretation means that the solution must make visual sense. If using a region/neighbourhood approach, one should arguably be more parsimonious, opting for two or three dimensions at most. This is the basis of Guttman's Smallest Space Analysis (Guttman, 1968), where solutions of least dimensionality are sought. Area or volume regions are readily interpretable; four-dimensional 'spaces' are not.

Two-dimensional solutions

Two-dimensional solutions usually have a poorer fit than three-dimensional solutions although any advantage afforded by the three dimensional fit may be marginal. Regions in two-dimensional maps will therefore cover larger areas than might concur with the data. Points that are, in fact, quite closely related may not map particularly close, affecting the stress of the particular solution. A poorer fit also means that some points external to a region may fall closer to it than data would indicate.

Three-dimensional solutions

Points have more space in which to 'distribute' so that distances in the map are a better fit with similarities in the data. However, in these maps, three-dimensional volumes are difficult to depict clearly and may have the effect of negating the better fit achieved. An alternative in this case is to draw two-dimensional representations of three-dimensional solutions, with the two most spread out dimensions projected onto the third. This technique, which was adopted by Bar-On and Perlberg (1985), is the preferred option in this study. A disadvantage is that two points may look close together, when, in fact, some distance in the third dimension separates them. Valid construction of regions based on other evidence (for example, actual correlation coefficients) should counteract such anomalies.

Hence, in this study, solutions of most appropriate dimensionality were chosen firstly on the basis of lower, but acceptable stress and high enough RSQ value. Because three-dimensional solutions were warranted, two-dimensional maps of three-dimensional solutions were constructed.

5.4.4 Comparison between maps

Direct comparison of maps can be achieved by ‘eyeballing’ or through intuition, both of which are fallible, or by a Procrustes analysis (Cox & Cox, 1994). To assist in the reliability of assumptions based on visual interpretation, all maps in a series have been drawn to the same scale. In this case, all maps have an x-axis of five units and a y-axis of four units. To reduce unnecessary ‘clutter’, these scales are not shown on any map.

The relative spread of regions may not be exactly comparable from one map to the next since each is independently determined by the iterative process of minimisation of discrepancies between distances and disparities. However, the data points are all between –1 and +1 because they are correlation coefficients, thus making it feasible for all maps to fit the same scale.

A Procrustes analysis provides a quantitative comparison of two configurations or maps. The Procrustes Statistic is a least squares measure of the minimised distances between corresponding points in two configurations. Low values indicate a close match. The root mean square (RMS) distance between common points indicates the average distance that the points on one map must move to coincide with corresponding points on the second map.

One cannot use a Procrustes statistic to determine statistically the degree to which one pattern differs from another, particularly if the data is correlational (Cox, M., personal communication, 2001). However, one *can* use the RMS distance to compare two or more pairs of maps to get an indication of the extent to which they are similar or different. These values have been calculated for different pairs of maps. The distances are relative to the scale of the maps, which is five units (x-axis) by four units (y-axis). The data is presented in Table 5.1 and referred to in the relevant sections that follow.

Table 5.1. Procrustes statistics and root mean square (RMS) distances between common points for the comparisons of corresponding pairs of maps.

Maps		**Procrustes statistic**	**RMS distance between common points**
1, 3	SI vs TI Initial (naïve EBs)	0.36	0.96
2, 4	SI vs TI Initial (sophisticated EBs)	0.50	1.11
1, 5	SI Initial vs SI Final (naïve EBs)	0.32	0.78
2, 6	SI Initial vs SI Final (sophisticated EBs)	0.52	1.02
3, 7	TI Initial vs TI Final (naïve EBs)	0.32	0.81
4, 8	TI Initial vs TI Final (sophisticated EBs)	0.53	1.04
9, 11	TI *Actual* vs SI *Actual* LE (naïve EBs)	0.46	1.09
10, 12	TI *Actual* vs SI *Actual* LE (sophisticated EBs)	0.43	0.97
11, 15	TI *Actual* vs TI *Preferred* LE (naïve EBs)	0.20	0.65
9, 13	SI *Actual* vs SI *Preferred* LE (naïve EBs)	0.089	0.35
12, 16	TI *Actual* vs TI *Preferred* LE (sophisticated EBs)	0.42	0.96
10, 14	SI *Actual* vs SI *Preferred* LE (sophisticated EBs)	0.13	0.46

Solutions of higher dimensionality should result in better matches between corresponding solutions. An important principle, as I see it, is that visual differences should be based more on differences in the existing learning environment and less on poorer fits with data. This is another reason why I have chosen three-dimensional solutions even though a two-dimensional solution might have been adequate.

5.5 Educational interpretation of maps

Interpretation of the meaning of maps will take up to four factors into account:

1. Nature of the variables in regions and the nature of the correlations among them.
2. Shape, size and distribution of regions.
3. Subsequent inferences about the students' learning, attitudes and beliefs.
4. Inferences about students' learning, attitudes and beliefs in relation to earlier data analyses.

Possible meanings that can be attached to regions will be illustrated below, using cognitive outcomes (COs) as an illustrative example.

Small, dense regions

The more points there are within a small region, that is the higher the density, the greater is their mutual association. A small, dense region, such as a tightly grouped CO region, indicates that students' results on the three tests/exams are highly inter-correlated. It tells us that some students tend to get high marks on all tests and some (different) students tend to get low marks on all tests. It indicates a consistency or maintenance of rank order of results over all tests.

Larger, diffuse regions

The more diffuse a region, the weaker are the inter-correlations. A more diffuse CO region, for example, tells us that there is a lower rank-order consistency between students' scores on different tests. Some students who score well in one test may achieve lower results in another. A student who scores a low result in one test is likely to be ranked higher in another test.

Although the density of points within a region tells us something about the strength of the interrelationships among the represented variables, it does not indicate that any one variable is the cause or effect of any of the others. Inferences about cause and effect, however, may be made with reference to other supporting data.

In practical terms, we can qualitatively compare two groups on the basis of the size or density of a CO region. Possible inferences that can be made relate to the extent to which a course enables students to achieve results that match their potential or ability at the time of sitting.

Interpretation of maps will be referenced to the learning model framework outlined in Figure 5.4. This was introduced in earlier chapters and is reproduced here.

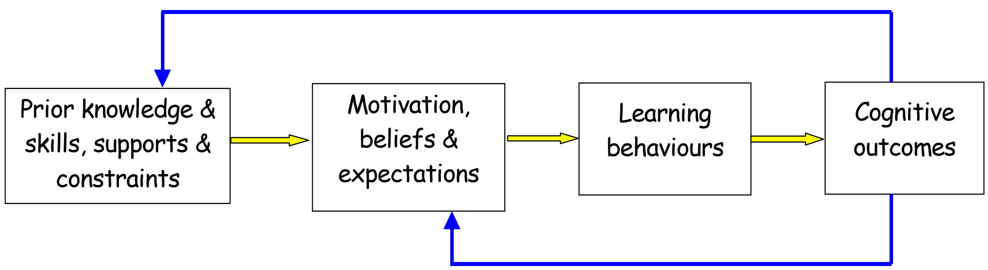

Figure 5.4. A learning model framework used to interpret students' learning.

Possible implications of a dense CO region

Optimal achievement: Students are achieving as well as they can, given their different prior knowledge and skills at the time of sitting the tests. [Although the opposite could also be true – that students are all achieving the worst possible results given their different prior knowledge and skills at the time of sitting the tests – it is an unlikely educational scenario.]

Beliefs and expectations: Students' have consistent beliefs about what is expected of them, and what to expect of each assessment, so that consistency of achievement is possible.

Goals and motivation: Student achievement is not unduly influenced by too many different or uncontrolled variables such as differences in goals or motivation. Where such differences exist, they impinge on student performance in a consistent way and not differently for different assessments.

Assessment type: Assessments are consistent in the types of skills and knowledge they require of students.

Chance: It is statistically possible, but not likely, that chance plays a part in the formation of small dense regions.

Hence a dense CO region might indicate *consistency of beliefs, motivation, learning behaviours and/or performance*.

Possible implications of a diffuse CO region

Variable achievement*:* Students do not achieve results consistent with their prior knowledge or skills at the time of the assessment. This will result in a lower rank order consistency from one assessment to another.

Beliefs and expectations: Students have inconsistent beliefs about what is expected of them, and what to expect of each assessment, so that consistency of achievement is not possible.

Goals and motivation: Students' individual achievements are more influenced by transitory or random attitudinal effects, goals and motivation, and that these affect a student's performance differently at different times or in different assessments.

Assessment type: Assessments are inconsistent in the types of skills and knowledge they require of students.

Randomness or chance: It is more likely that a diffuse rather than dense region will result. One can draw a parallel with the concept of entropy or tendency toward disorder to explain this.

Hence a diffuse CO region might indicate *variability or inconsistency of beliefs, motivation, learning behaviours and/or performance*.

5.6 Analysis of maps - Part I

As a reminder, the following colour codes were used to identify regions:

Solid black lines are drawn between all points/variables that have a significant, positive correlation. **Solid pink lines** are drawn between all variables that have a significant, negative correlation. **Dotted black lines** are drawn between all variables that have positive correlations greater than 0.2, but are non-significant. **Dotted pink lines** are drawn between all variables that have negative correlations less than -0.2, but are non-significant. Map symbols are shown in Figure 5.5.

▲	IT self-efficacy beliefs
○	Epistemological belief – 'naïve' as high score
●	Epistemological belief – 'sophisticated as high score
◆	Learning environment – Student Communication & Reflection
◇	Learning environment – Teacher Interpersonal Qualities
■	Cognitive status or outcomes

Figure 5.5. Legend for symbols on MDS maps.

5.6.1 Map Series I – Cognitive outcomes, epistemological beliefs and IT self-efficacy beliefs (CO/EB/IT) maps

SI students' initial maps

Figures 5.6A and 5.6B (Maps 1A & B): Correlations and associations among **SI** students' *naive* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *beginning* of the year.

Figures 5.7A and 5.7B (Maps 2A & B): Correlations and associations among **SI** students' *sophisticated* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *beginning* of the year.

NB. Maps 1 and 2 are alternative representations of the **same data**. For map 2, the correlations between epistemological beliefs and all other variables (but themselves) have been reversed in sign.

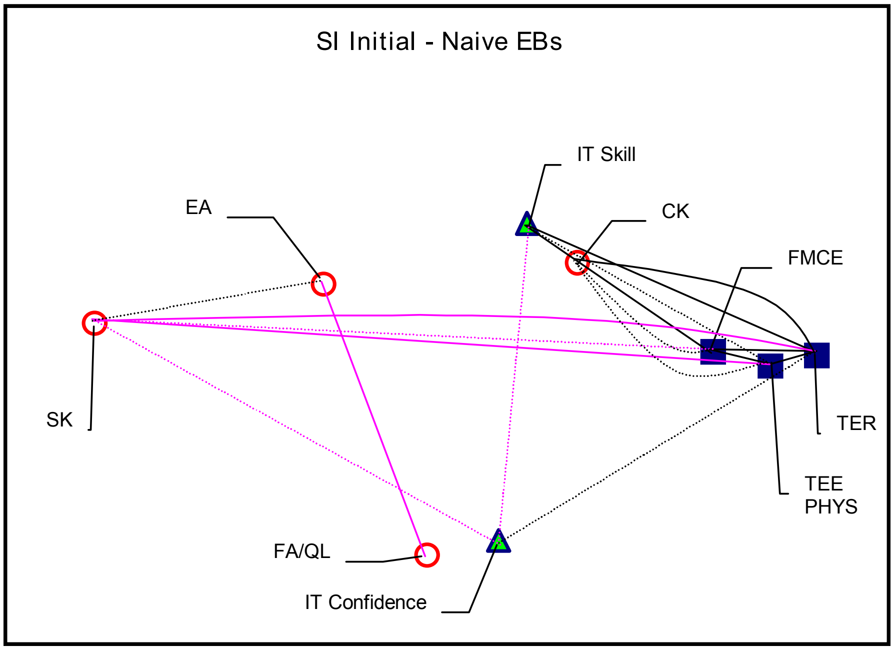

Figure 5.6A. Map 1A – showing ***correlations*** *among SI students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive status at the beginning of the year.*

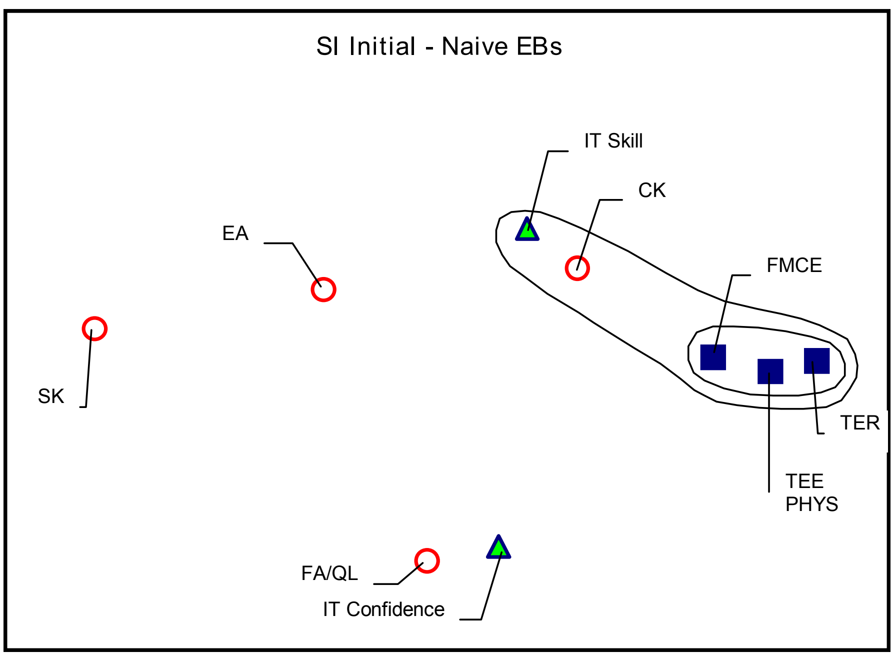

Figure 5.6B. Map 1B – showing SI students at the beginning of the year, showing regions of association and ***interrelationships*** *between students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive status.*

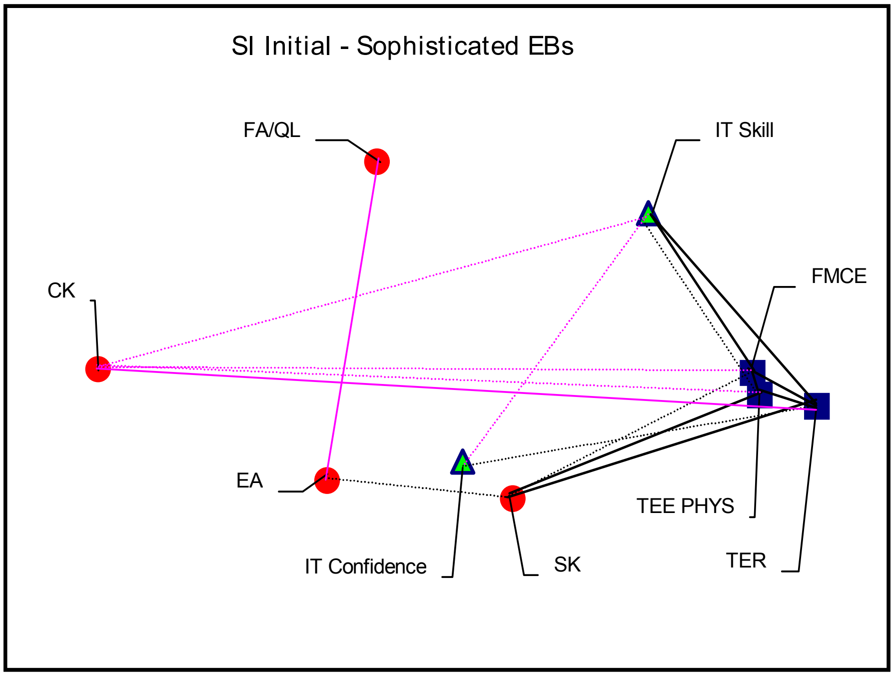

*Figure 5.7A. Map 2A – showing **correlations** among SI students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive status at the beginning of the year.*

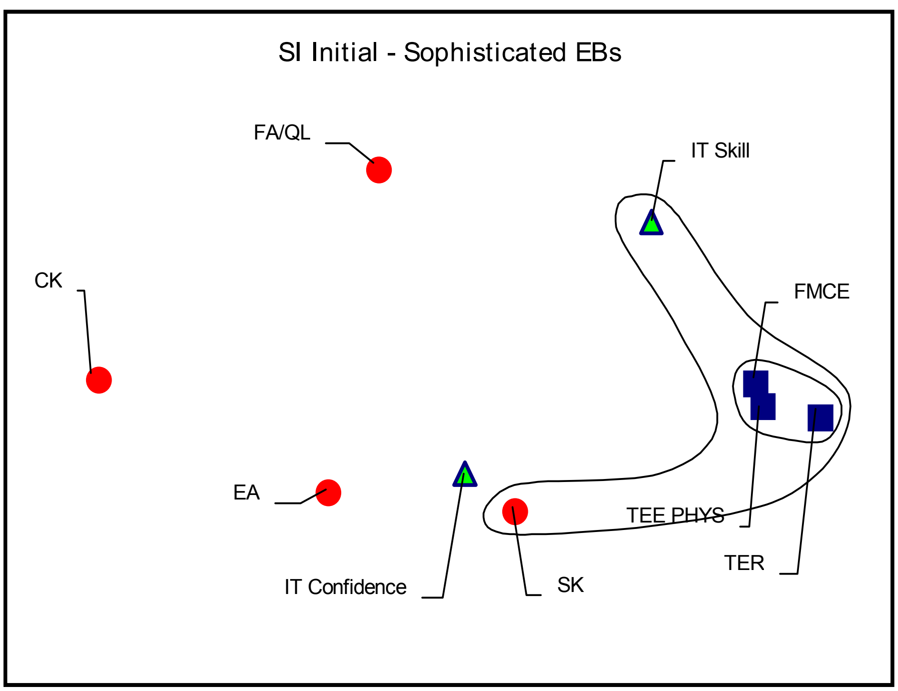

*Figure 5.7B. Map 2B – showing SI students at the beginning of the year, showing regions of association and **interrelationships** between students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive status.*

Interpretation of maps 1 and 2

As expected, the maps have similar internal structures for cognitive status, IT Skill and IT Confidence. The cognitive status region is compact. SI students have highly inter-correlated, consistent results on their TEE physics examinations, TERs and FMCE pretests.

Students' belief about their IT Skill is weakly associated with higher cognitive status. Students with higher results on these tests tend to rate themselves as having better computer-related skills. There is no apparent relationship between IT skill and IT confidence implying that students who rate themselves as having better computer-related skills do not necessarily see the technology having any particular value for them; the same for students who rate themselves as having lower computer-related skills.

The epistemological belief points are spread out with only Simple Knowledge and Certain Knowledge being related to cognitive status. Both maps show that students who have higher cognitive status tend to have more sophisticated beliefs in Simple Knowledge (shown by the close proximity between the cognitive status region and Simple Knowledge in Map 2), and that students who have lower cognitive status tend to have more naïve beliefs in Simple Knowledge (shown by the distance between cognitive status regions and SK in Map 1). This means that students with higher cognitive status (marks) tend to believe that knowledge consists of highly interrelated concepts rather than consisting of discrete and unrelated facts.

On the other hand, both maps (in particular map 1) show that students who have higher cognitive status tend to have less sophisticated (more naïve) beliefs in Certain Knowledge, i.e. that knowledge is fixed and not tentative and evolving.

TI students' initial maps (and comparison with SI students' initial maps)

Figures 5.8A and 5.8B (Maps 3A & B): Correlations among **TI** students' *naive* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *beginning* of the year.

Figures 5.9A and 5.9B. (Maps 4A & B): Correlations among **TI** students' *sophisticated* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *beginning* of the year.

NB. Maps 3 and 4 are alternative representations of the same data. For map 4, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

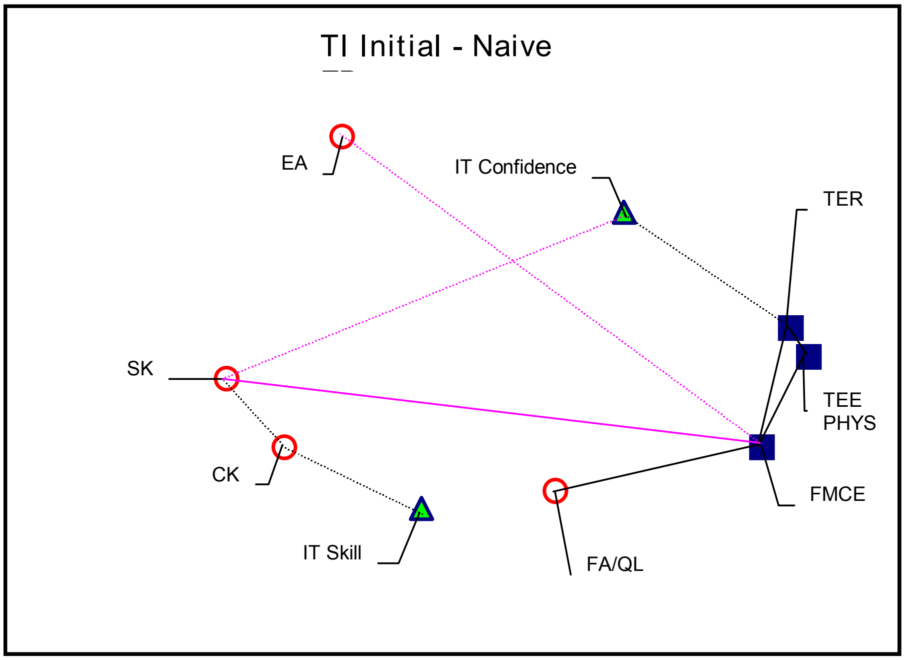

*Figure 5.8A. Map 3A - showing **correlations** among TI students' naïve epistemological beliefs, IT self-efficacy beliefs and cognitive status at the beginning of the year.*

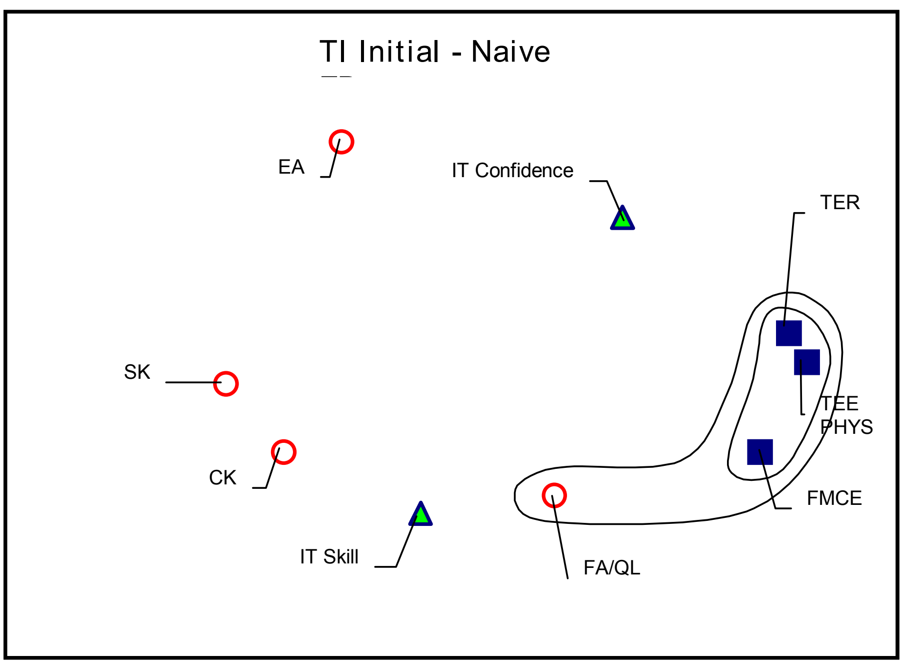

*Figure 5.8B. Map 3B - showing TI students at the beginning of the year, showing regions of association and **interrelationships** between students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive status.*

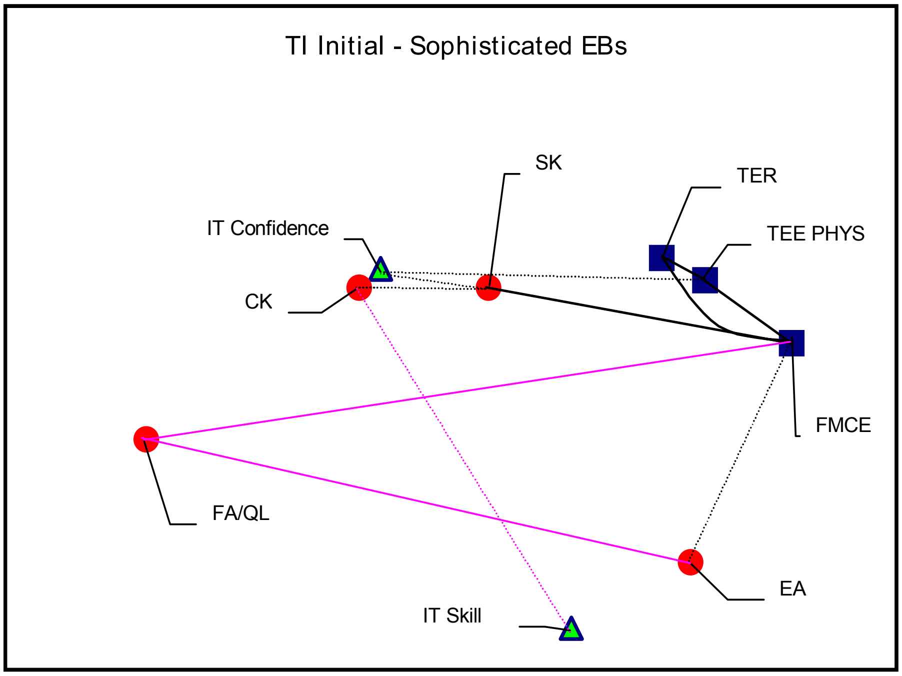

Figure 5.9A. Map 4A - showing ***correlations*** *among TI students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive status at the beginning of the year.*

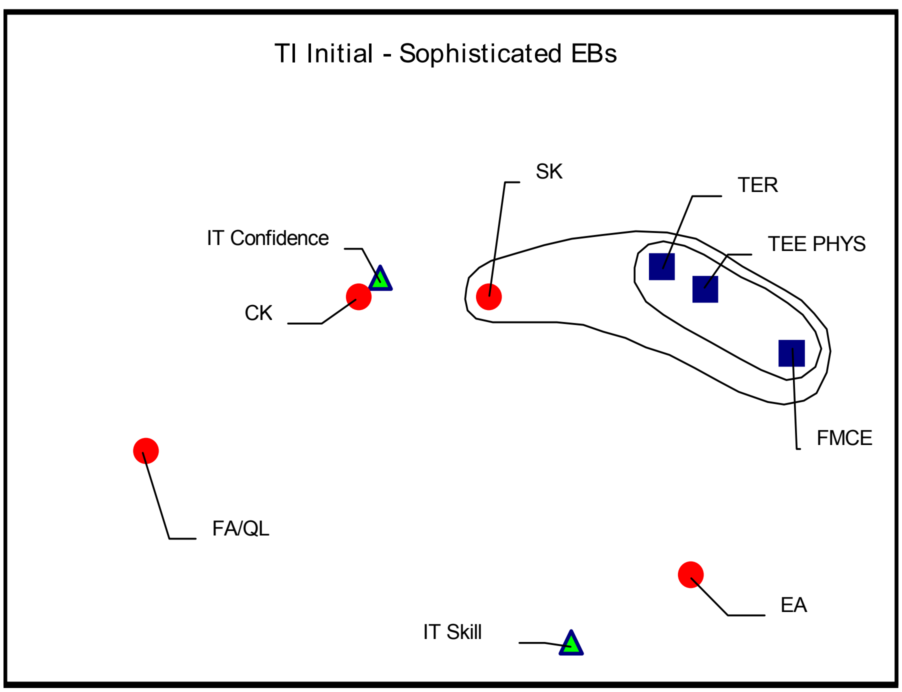

Figure 5.9B. Map 4B - showing TI students at the beginning of the year, showing regions of association and ***interrelationships*** *between students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive status.*

Interpretation of maps 3 and 4

Like the SI maps, these maps have a similar overall structure for cognitive status and IT skill and confidence. Although there is a less compact cognitive status region than in the SI maps, TI students still have significantly inter-correlated results on their TEE physics examinations, TERs and FMCE pretests. In comparison with SI students, however, TI students' marks are possibly less consistent.

There is no relationship between IT skill and cognitive status, and no apparent relationship between IT skill and IT confidence.

The epistemological belief points are similarly spread out with only Simple Knowledge and Fixed Ability/Quick Learning being related to cognitive status. Both maps show that TI students who have higher cognitive status tend to have more sophisticated beliefs in Simple Knowledge, i.e. that knowledge consists of highly interrelated concepts and that those who have lower cognitive status tend to have more naïve beliefs in Simple Knowledge, i.e. that knowledge is discrete and unambiguous.

A more obvious difference between TI and SI students is that TI students who have higher cognitive status tend to have more naive beliefs in Fixed Ability/Quick Learning i.e. that ability to learn is not malleable and that learning occurs quickly. Students who have lower cognitive status tend to have more sophisticated beliefs in Fixed Ability/Quick Learning i.e. that ability to learn can be changed and that learning is a gradual process.

Comparison between SI and TI students on course entry (maps 1 through 4):

- SI students are more consistent in cognitive status than TI students, that is, SI students with high scores on one measure of prior cognitive ability also tend to have higher scores on the other measures.
- Higher cognitive status is associated with more sophisticated belief in Simple Knowledge for both groups.
- Higher cognitive status is associated with more *naïve* beliefs in Certain Knowledge for SI students and Fixed Ability/Quick Learning for TI

students. It is possible that prior physics experience may support beliefs in the *certainty of knowledge* and the *innate, fixed ability of individuals*.

- For SI students there is an association between IT skill and cognitive status.

Procrustes Analysis

A Procrustes analysis is a statistical comparison of the similarity between two MDS configurations (see Section3 3.3.4 and 5.4.4). The Procrustes statistic for the comparison between maps 1 and 3 (SI initial, naïve EBs and TI initial, naïve EBs) is 0.36 (RMS distance = 0.96 units) and for the comparison between maps 2 and 4 (SI initial, sophisticated EBs and TI initial, sophisticated EBs) is 0.50 (RMS distance = 1.11 units). See Table 5.1. This indicates there is a greater difference between the configurations when expressed in the sophisticated form than when expressed in the naïve form. This can be explained by the positioning of the EB points alone – in that strong positive correlations, which tend to 'pull' the points together, become strong negative correlations when the signs are reversed. This has the effect of increasing inter-point spacing. The difference is not readily visually obvious.

How does this translate into a difference between the groups? It appears to indicate that students with more naïve epistemological beliefs are more similar in their cognitive status and IT self-efficacy beliefs irrespective of the group they are in. Students with more sophisticated epistemological beliefs are more varied in cognitive status and IT self-efficacy beliefs.

Supporting information from earlier analyses: Both groups were equivalent in their results on TEE physics, TER and FMCE (equal means), SI students believed themselves to be less skilled at using IT than did TI students and SI students were more sophisticated (less naïve) in belief in Simple Knowledge.

Hence, despite the allocation of students to 'matched groups', these maps indicate that there were minor differences between the groups on course entry. If we relate this to the learning model framework, the two groups differ in their psychological dispositions, i.e. some self-efficacy beliefs, epistemological beliefs and possibly goals and motivation. The differences are more evident in students with more sophisticated epistemological beliefs. The extent to which prior physics instruction has engendered these beliefs, or to which these beliefs have prompted students to choose to study physics at university is unknown.

SI students' final maps (in comparison with initial maps)

Figures 5.10A and 5.10B (Maps 5A & B): Correlations among **SI** students' *naive* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *end* of the year.

Figures 5.11A and 5.11B (Maps 6A & B): Correlations among **SI** students' *sophisticated* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *end* of the year.

NB. Maps 5 and 6 are alternative representations of the same data. For map 6, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

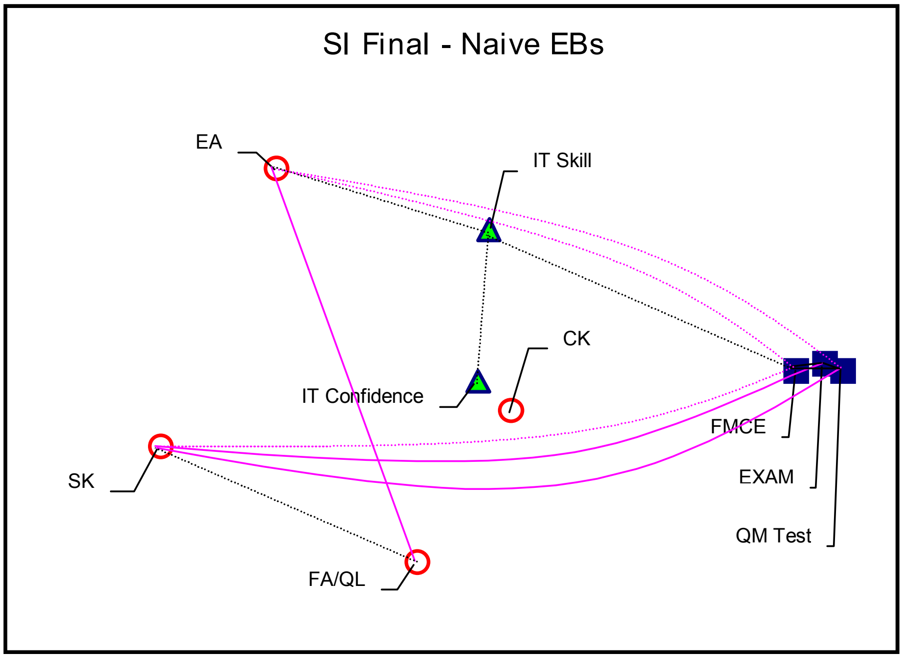

*Figure 5.10A. Map 5A – showing **correlations** among SI students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes at the end of the year.*

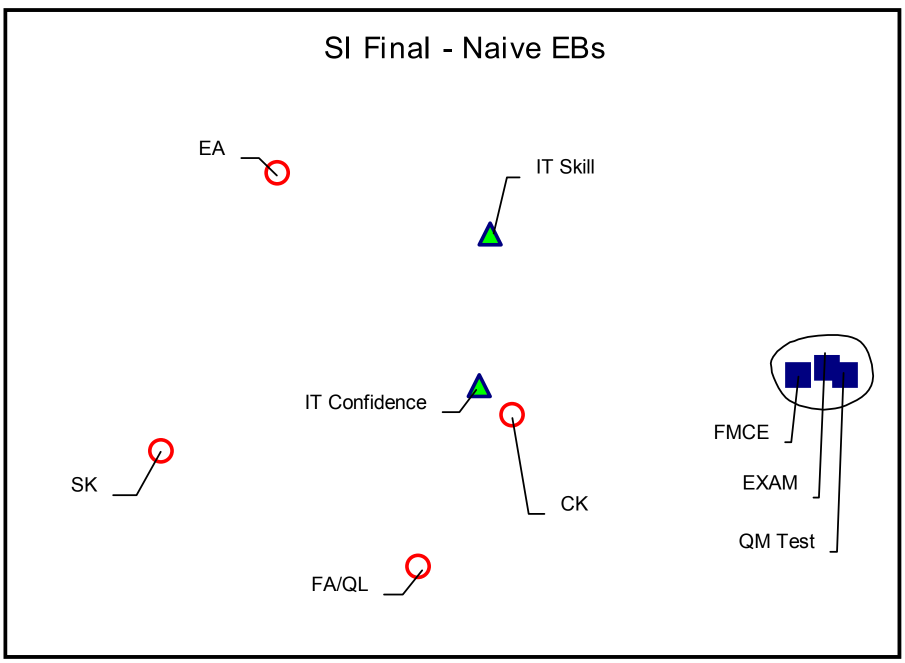

*Figure 5.10B. Map 5B – showing SI students at the end of the year, showing regions of association and **interrelationships** between students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes.*

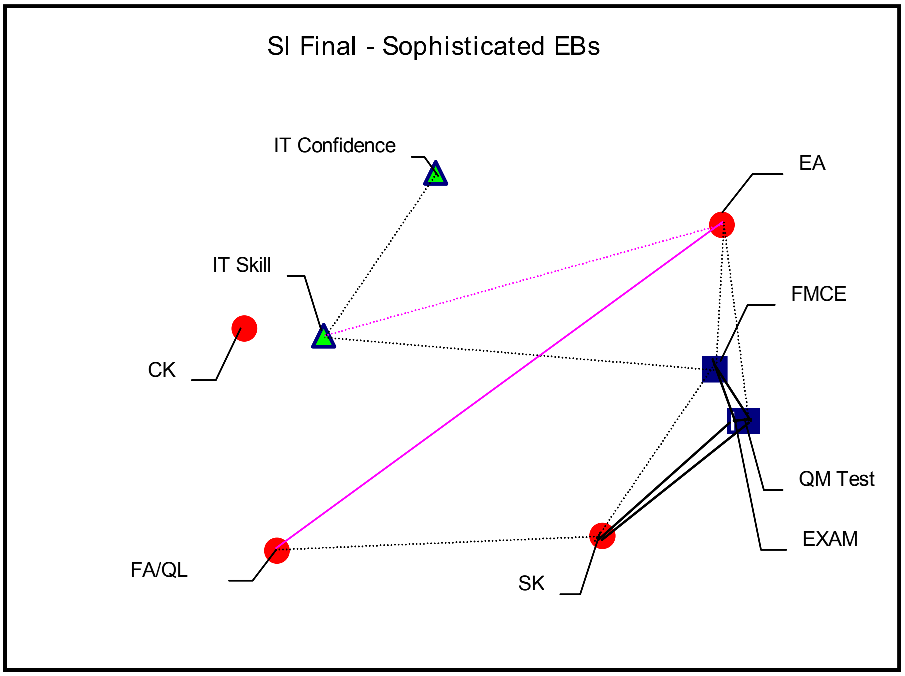

Figure 5.11A. Map 6A – showing ***correlations*** *among SI students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes at the end of the year.*

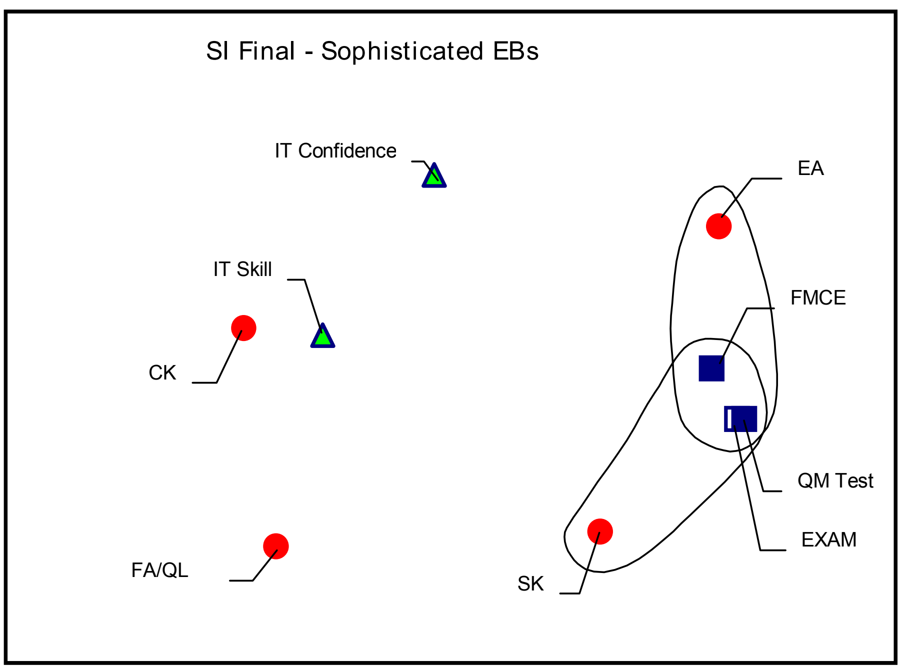

Figure 5.11B. Map 6B – showing SI students at the end of the year, showing regions of association and ***interrelationships*** *between students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes.*

Interpretation of maps 5 and 6

The cognitive outcomes group is still tightly clustered.

Naïve belief in Certain Knowledge is now no longer associated with higher cognitive outcomes (map 5) but more sophisticated beliefs in Simple Knowledge and Expert Authority are (map 6).

The association between cognitive outcomes and sophisticated belief in Simple Knowledge has remained strong. Students with the higher cognitive outcomes tend to have more sophisticated beliefs in Simple Knowledge and in Expert Authority, although they are not necessarily the same students. Students with lower cognitive outcomes tend to have more naïve beliefs in the same dimensions.

Belief in Certain Knowledge has moved to a more central position. Hence, some SI students appear to have changed in their beliefs about the role of experts or authority figures as the source of knowledge. I indicated in Chapter 4 that there might have been a change toward less naïve (or more sophisticated) belief in Certain Knowledge – and we see here and indication of less of a relationship between cognitive outcomes and belief in the *certainty of knowledge.*

IT Skill has moved away from the cognitive outcomes cluster and is now more closely associated with IT Confidence. SI students appear to have a new understanding of the use and personal value of information technology; the greater they perceive their skill to be, the more they feel confidence in its use and its value.

Procrustes analysis

The Procrustes statistic for the comparison between maps 1 and 5, and maps 2 and 6 (SI initial and SI final) is 0.32 (RMS distance = 0.78 units) for the 'naïve' maps and 0.52 (RMS distance = 1.02 units) for the 'sophisticated' maps. See Table 5.1. This shows again a greater difference between configurations when expressed in the sophisticated form than when expressed in the naïve form. In this case, it appears to indicate that there is less change among students with more naïve epistemological beliefs than among students with more sophisticated epistemological beliefs from the beginning to the end of the year.

TI students' final maps (in comparison with initial maps)

Figures 5.12A and 5.12B (Maps 7A & B): Correlations among **TI** students' *naive* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *end* of the year.

Figures 5.13A and 5.13B (Maps 8A & B): Correlations among **TI** students' *sophisticated* epistemological beliefs, IT self-efficacy beliefs and cognitive status at the *end* of the year.

NB. Maps 7 and 8 are alternative representations of the same data. For map 8, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

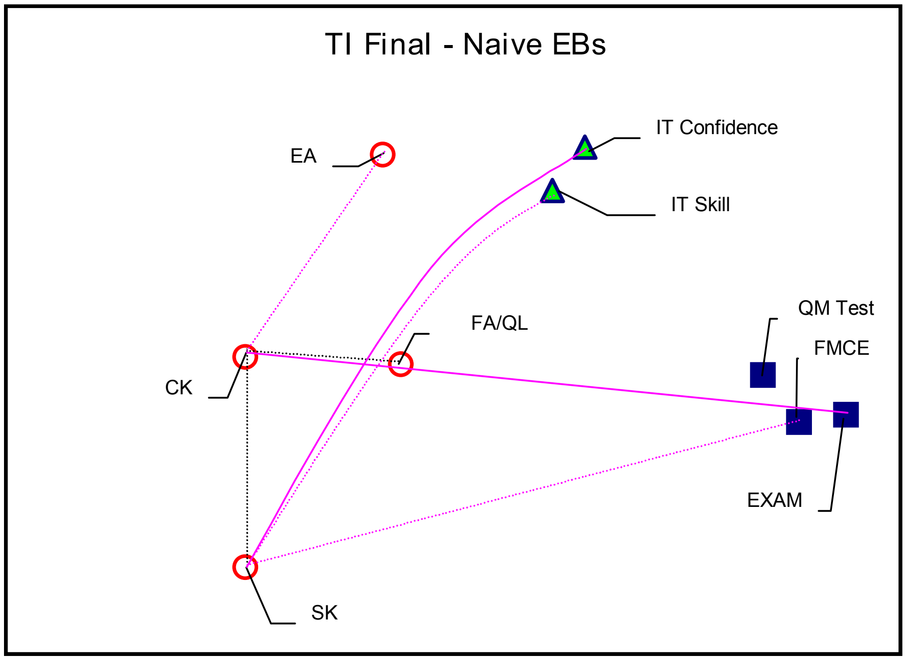

Figure 5.12A. Map 7A – showing ***correlations*** *among TI students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes at the end of the year.*

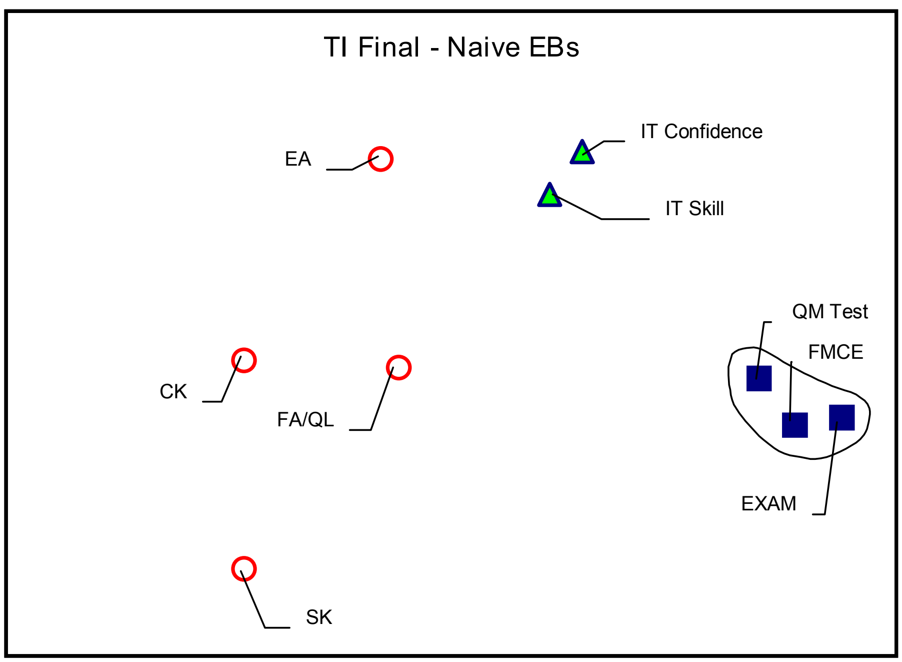

Figure 5.12B. Map 7B – showing TI students at the end of the year, showing regions of association and ***interrelationships*** *between students' naive epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes.*

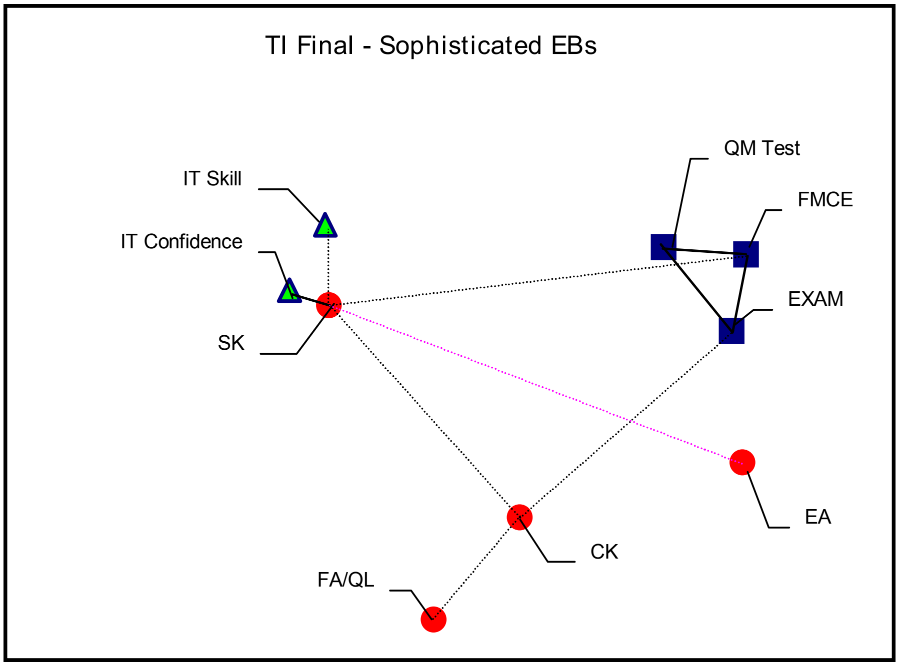

*Figure 5.13A. Map 8A – showing **correlations** among TI students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes at the end of the year.*

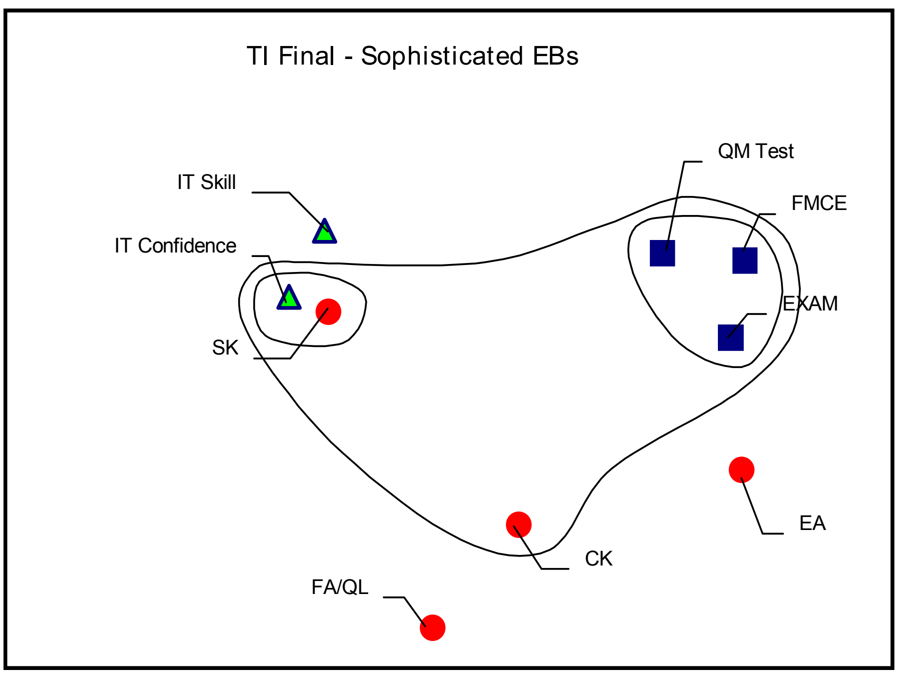

*Figure 5.13B. Map 8B – showing TI students at the end of the year, showing regions of association and **interrelationships** between students' sophisticated epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes.*

Interpretation of maps 7 and 8

The cognitive outcomes group appears no more tightly clustered than at the beginning of the year.

Naïve belief in Fixed Ability/Quick Learning is now no longer associated with cognitive outcomes (map 7), having moved to a more central position.

The association between cognitive outcomes and sophisticated belief in Simple Knowledge has deteriorated and there are now no close associations between sophisticated epistemological beliefs and higher cognitive outcomes (map 8). The deterioration in belief in Simple Knowledge identified in Chapter 5 thus appears to have been in the students with higher cognitive outcomes. Students with the higher cognitive outcomes still tend to have less naïve (more sophisticated) beliefs but the association is weak. Map 7 in particular, illustrates the separateness of epistemological beliefs, cognitive outcomes and IT self-efficacy belief groups for TI students.

IT Skill is not particularly associated with IT Confidence. There is a separation in the third dimension that does not show up in this two-dimensional representation. However, it appears that both may be linked to a more sophisticated belief in Simple Knowledge. The more that students believe knowledge is complex and interrelated, the higher they rate their IT Skill and value for the use of IT.

Procrustes analysis:

The Procrustes statistic for the comparison between maps 3 and 7, and 4 and 8 (TI initial and TI final) is 0.32 (RMS distance =0.81 units) for the 'naïve' maps and 0.53 (RMS distance = 1.04 units) for the 'sophisticated' maps. See Table 5.1. These differences are almost the same as for the SI group. Thus, both groups' maps have changed by a similar amount. Similarly, there appears to be less change among students with more naïve epistemological beliefs than among students with more sophisticated epistemological beliefs from the beginning to the end of the year.

Comparison between SI and TI students on course exit (Maps 5-8).

Similar features of both SI and TI Maps:

- The densities of the cognitive outcomes regions have remained essentially unchanged for each group.
- Sophisticated belief in Simple Knowledge is associated with higher cognitive outcomes.
- There is no apparent link between beliefs in Certain Knowledge and Fixed Ability/Quick Learning and high cognitive outcomes (i.e. both are central).

Dissimilar features of both SI and TI Maps:

- For SI students, there is a stronger association between high cognitive outcomes and sophisticated belief in Simple Knowledge and Expert Authority. For TI students, there is a weaker association between high cognitive outcomes and sophisticated belief in Simple Knowledge and Certain Knowledge.
- SI students' IT self-efficacy beliefs are linked and have changed over the year whereas there has been no apparent change for TI students.

5.6.2 Summary of observations and conclusions from Maps 1-8

The following **conclusions** (Table 5.2) are drawn in relation to SI students' interrelationships between epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs (in comparison with TI students), and how they have changed over two semesters.

Table 5.2. Observations and conclusions for SI students' interrelationships between epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs.

Observations	Conclusions
Cognitive outcomes:	
The density of the cognitive outcomes region has remained essentially unchanged over the year, and has remained denser than the TI students' CO region.	SI students have been consistent in achievement on various types of assessment tests. Students' beliefs, expectations, goals and motivation affect them in consistent ways.
Epistemological beliefs:	
A continued strong association between sophisticated belief in SK and high cognitive outcomes. An increased association between sophisticated belief in EA and high cognitive outcomes. A decrease in association between naïve belief in CK and high cognitive outcomes.	SI students have generally undergone a move away from an association between naïve epistemological beliefs (CK) and higher cognitive outcomes toward an association between more sophisticated epistemological beliefs (SK, EA) and high cognitive outcomes. [A similar trend is seen for TI students' beliefs in CK and FA/QL but the evidence points to a much smaller effect.]
IT self-efficacy beliefs:	
SI students' IT self-efficacy beliefs have become linked over the year whereas there has been no apparent change for TI students' beliefs.	SI Students' exposure to the integral use of computers in their learning has resulted in changed IT self-efficacy beliefs. Perceived IT skill is associated with perceived IT confidence (value for the technology). These are not related to students' cognitive outcomes.

5.7 Analysis of maps – Part II

5.7.1 Map Series II - cognitive outcomes, epistemological beliefs, IT self-efficacy beliefs and learning environment (CO/EB/LE) maps

SI students' maps of their *Actual* learning environment

Figures 5.14A and 5.14B (Maps 9A & B): Correlations among **SI** students' *naive* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Actual* learning environment assessments.

Figures 5.15A and 5.15B (Maps 10A & B): Correlations among **SI** students' *sophisticated* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Actual* learning environment assessments.

NB. Maps 9 and 10 are alternative representations of the same data. For map 10, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

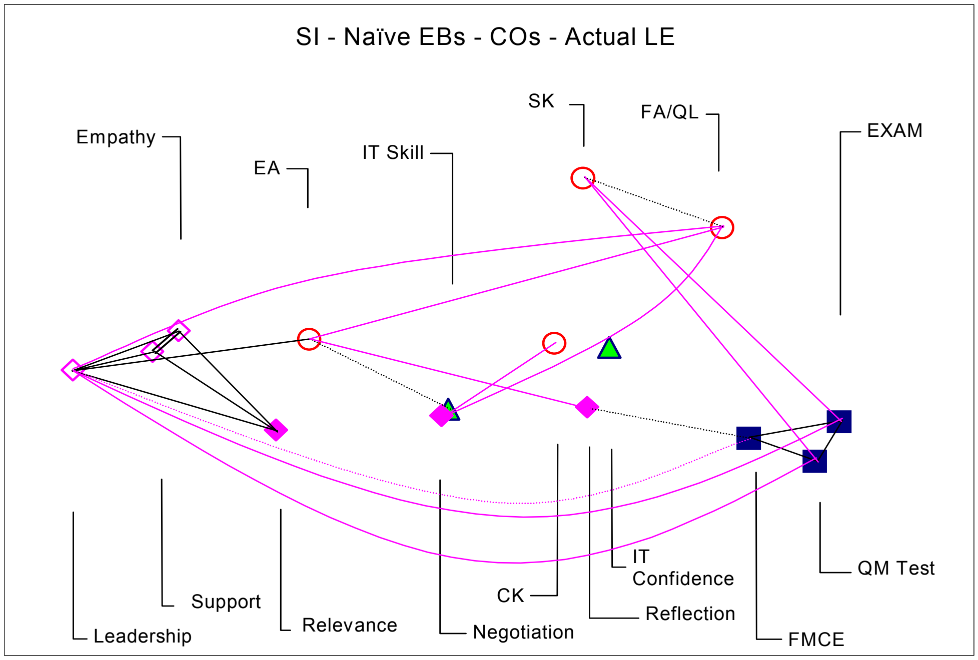

*Figure 5.14A. Map 9A – showing **correlations** among SI students' 'naive' epistemological beliefs, assessments of their Actual learning environment and cognitive outcomes.*

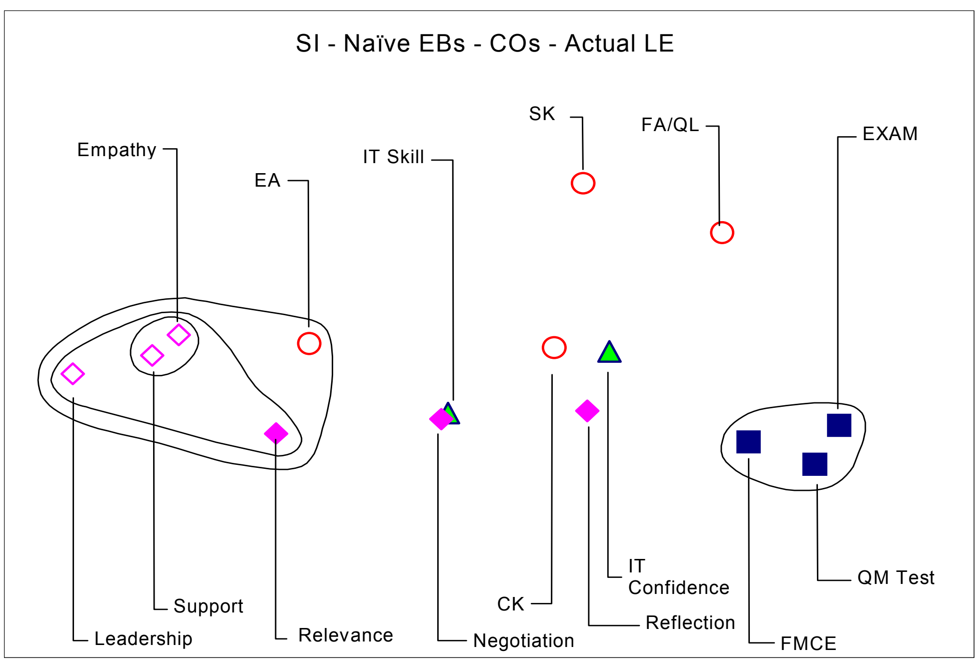

*Figure 5.14B. Map 9B – showing regions of association and **interrelationships** between SI students' 'naïve' epistemological beliefs, assessment of their Actual learning environment and cognitive outcomes.*

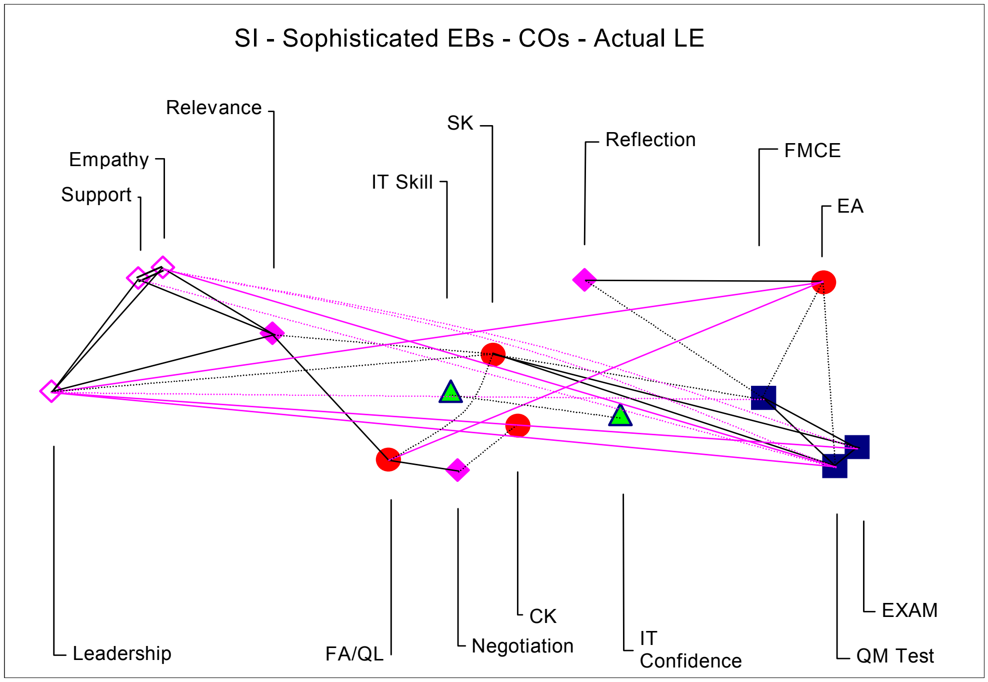

Figure 5.15 A. Map 10 A – showing ***correlations*** *among SI students' 'sophisticated' epistemological beliefs, assessments of their 'Actual' LE and cognitive outcomes.*

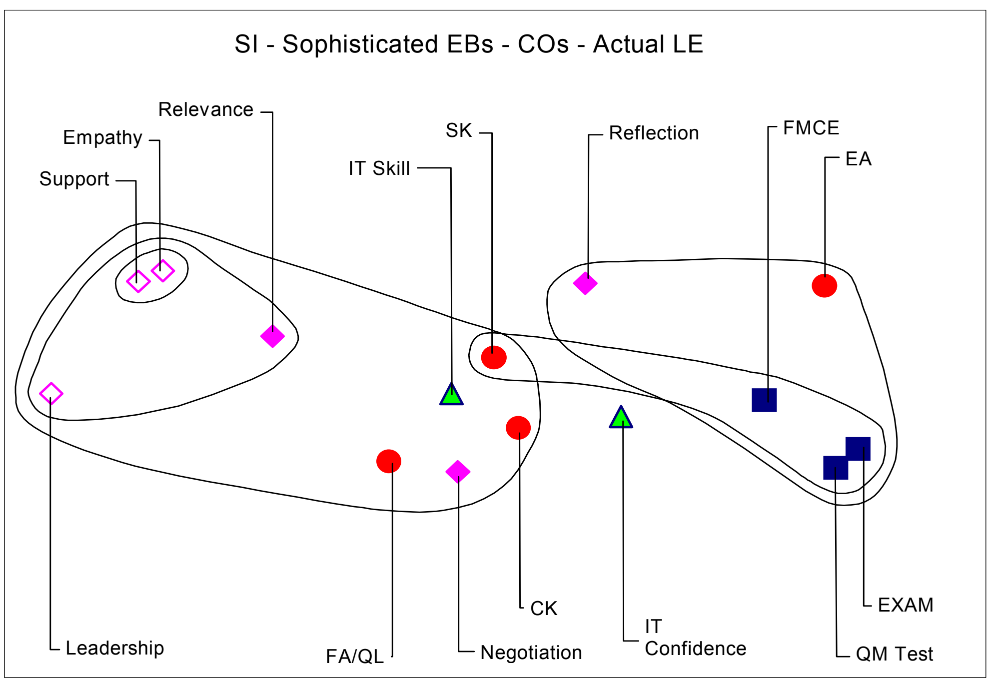

Figure 5.15B. Map 10B – showing regions of association and ***interrelationships*** *between SI students' sophisticated epistemological beliefs, assessment of their Actual LE and cognitive outcomes.*

Interpretation of maps 9 and 10

These maps use the same data as Maps 5 and 6 with *Actual* learning environment data added. Hence, there should be a visual similarity between the *naïve* epistemological belief maps (9 and 5) and the *sophisticated* epistemological belief maps (10 and 6). Note also that maps 9 and 10 should show similar configurations for cognitive outcomes, IT self-efficacy beliefs and learning environment scores. The difference between the two is the location of epistemological beliefs, with Map 9 showing *naïve* epistemological beliefs as the high score and Map 10 showing *sophisticated* epistemological beliefs as the high score. Hence, all conclusions drawn from analyses of maps 5 and 6 are applicable here.

There is a wide separation between cognitive outcomes and learning environment scores. This is due to the negative correlations between several learning environment scales and cognitive outcomes and supported by the high inter-correlations among the learning environment scales. SI students with the higher cognitive outcomes are the ones who rate the *Actual* learning environment, in particular Support, Empathy and Leadership and Relevance, lower. It seems plausible that the students with higher cognitive outcomes are not the ones who seek or need the Leadership, Support and Empathy of teachers. The converse, however, is also the case – that students with lower cognitive outcomes tend to rate these qualities of the learning environment higher i.e. they feel that they are given a high degree of Leadership, Support and Empathy.

Learning environment

Students are consistent in their assessment of Support and Empathy, both of which are closely linked to Leadership. These are the three scales that measure Teacher Interpersonal Qualities. Students who rate the learning environment highly in any one of these tend to rate the others highly as well. The converse is also true; those who rate the learning environment low on one scale tend to rate it low on the others. Relevance and naïve belief in Expert Authority are also linked to these scales. Students who tend to see the physics as not relevant to their everyday lives are the ones who perceive less Support, Empathy and Leadership from their teachers, and also tend to believe that the role of experts (authority) is to deliver knowledge to them. Those who perceive more Support, Empathy and Leadership from their teachers are the ones who tend to believe that knowledge is developed by individuals rather than given by experts. They also tend to see the physics as more relevant to them.

Other aspects of the learning environment, Negotiation and Reflection, are more central, being neither linked to other learning environment scales nor to cognitive outcomes. Reflection (reflective thinking) was the learning environment scale given the lowest rating by SI students. However, Reflection is the one learning environment scale consistently linked to the cognitive outcomes region.

Naïve beliefs in Simple Knowledge and Fixed Ability/Quick Learning are negatively correlated with **both** cognitive outcomes and learning environment assessment (see map 9A & B). This illustrates that students with more naïve beliefs tend to have lower cognitive outcomes and to rate the learning environment, in particular Teacher Interpersonal Qualities, less ‘constructivist’ than students with more sophisticated beliefs.

The pattern of interrelationships in Map 10 (sophisticated beliefs as high score) shows more positive correlations than negative correlations, introduced by the reversed epistemological belief correlations. It is a more complex map with many associations. There are two diffuse but overlapping regions and an almost continuous linkage of positive correlations between test results, through sophisticated epistemological beliefs across to learning environment assessment. Students’ sophisticated beliefs in Simple Knowledge and Expert Authority are linked to cognitive outcomes, and sophisticated belief in Fixed Ability/Quick Learning is linked to learning environment assessment. This map suggests that SI students with more sophisticated beliefs tend to have higher results and also perceive their learning environment more positively than students with more naïve beliefs.

TI students' maps of their *Actual* learning environment

Figures 5.16A and 5.16B (Maps 11A & B): Correlations among **TI** students' *naive* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Actual* learning environment assessments.

Figures 5.17A and 5.17B (Maps 12A & B): Correlations among **TI** students' *sophisticated* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Actual* learning environment assessments.

NB. Maps 11 and 12 are alternative representations of the same data. For map 12, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

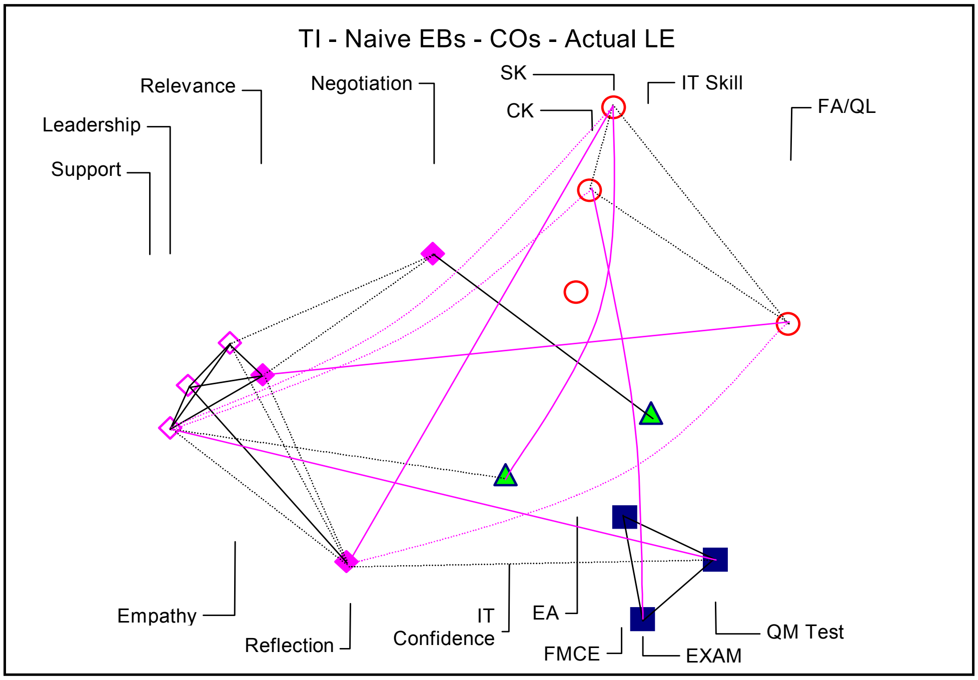

*Figure 5.16A. Map 11A – showing **correlations** among TI students' 'naive' epistemological beliefs, assessments of their Actual LE and cognitive outcomes.*

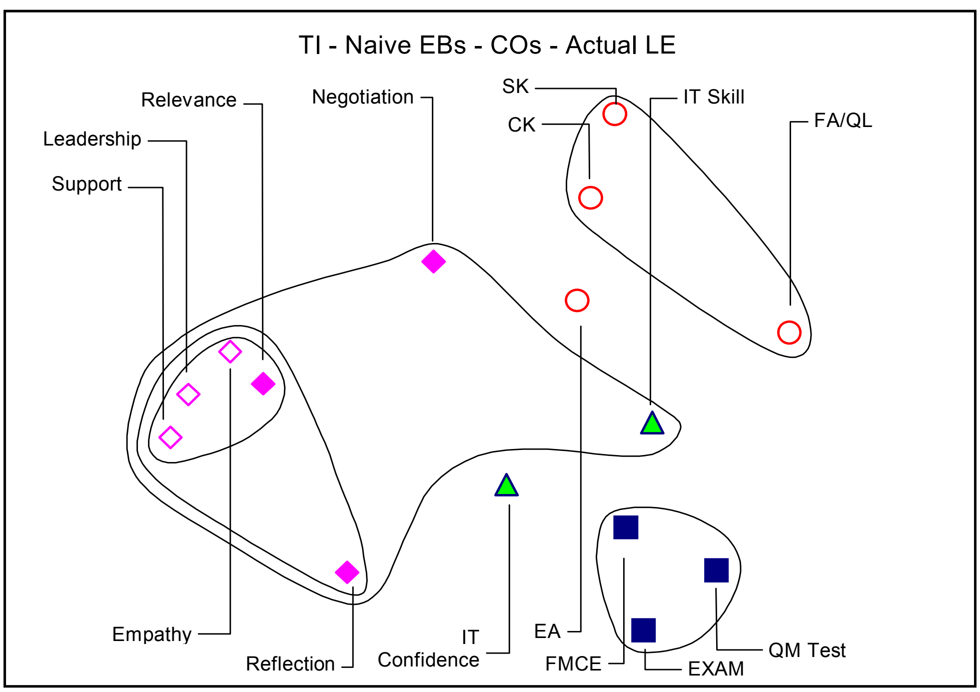

*Figure 5.16B. Map 11B – showing regions of association and **interrelationships** between TI students' 'naïve' epistemological beliefs, assessments of their Actual LE and cognitive outcomes.*

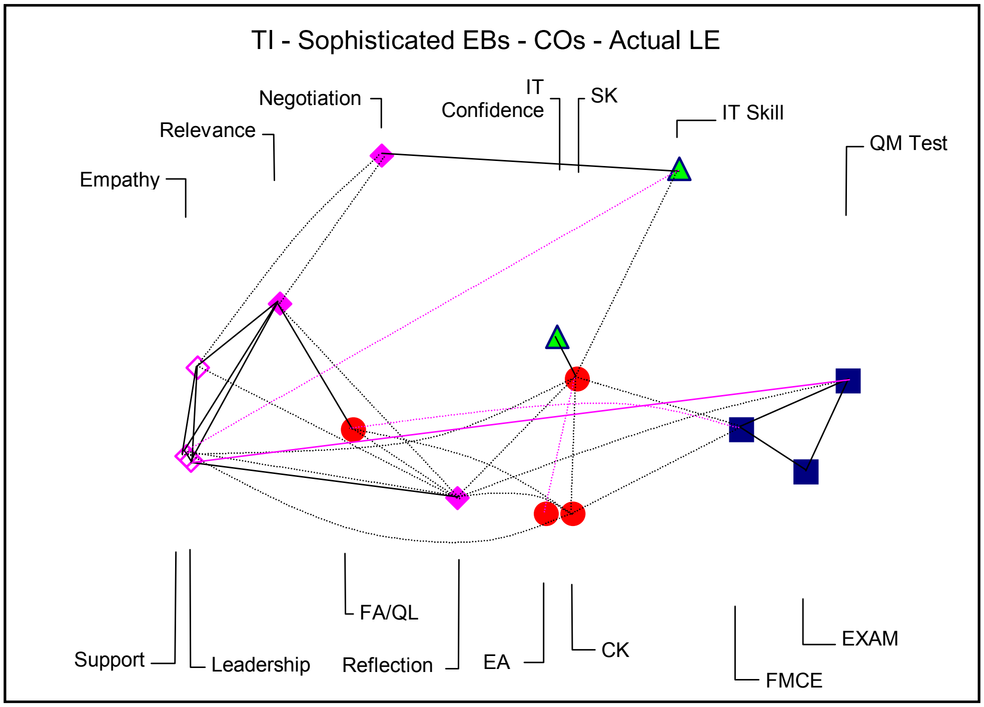

*Figure 5.17A. Map 12A – showing **correlations** among TI students' 'sophisticated' epistemological beliefs, assessments of their Actual LE and cognitive outcomes.*

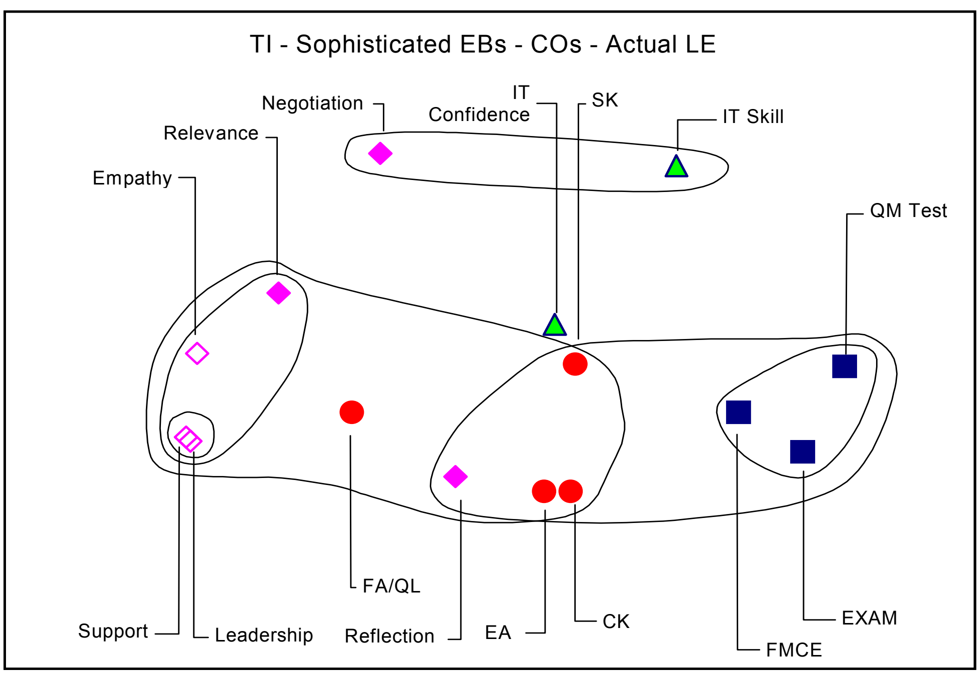

*Figure 5.17B. Map 12B – showing regions of association and **interrelationships** between TI students' 'sophisticated' epistemological beliefs, assessments of the Actual LE and cognitive outcomes.*

Interpretation of maps 11 and 12

These maps use the same data as Maps 7 and 8 with *Actual* learning environment data added. As with the corresponding SI maps, there should be a visual similarity between the *naïve* epistemological belief maps (11 and 7) and the *sophisticated* epistemological belief maps (12 and 8). Map 7 and Map 11 (minus the LE data points) are, in fact, quite similar although they may not appear so. The apparent inconsistency is due to the reflection and rotation of groups in three dimensions. Note also that Maps 11 and 12 should show similar configurations for cognitive outcomes, IT self-efficacy beliefs and learning environment assessments. The difference between the two is the location of epistemological beliefs, with Map 11 showing *naïve* epistemological beliefs as the high score and Map 12 showing *sophisticated* epistemological beliefs as the high score. Hence, all conclusions drawn from analyses of maps 7 and 8 are applicable here.

As seen in the corresponding SI maps (9 & 10), there is a close grouping of the learning environment scales Leadership, Empathy and Support, together with Relevance. TI students tend to associate Support with Leadership whereas SI students tend to closely associate Support with Empathy. This is explainable if one considers the closer links between SI students and teachers than between TI students and lecturers/tutors.

There is a wide separation between the cognitive outcomes region and learning environment region, but this is not as wide as in the SI maps. Hence, TI students with higher cognitive outcomes also tend to rate the learning environment less ‘constructivist’ than students with lower cognitive outcomes.

The learning environment region is widely separated from the cognitive outcomes region, and the *naïve* epistemological belief grouping (SK, CK and FA/QL) is located some distance from **both** regions (Map 11). This suggests that students with more naïve beliefs tend to have lower cognitive outcomes **and** to rate the learning environment, in particular Teacher Interpersonal Qualities, less ‘constructivist’ than students with more sophisticated beliefs. The SI Map 9 shows a similar configuration although with TI students there is a more definite association between students’ beliefs in Simple Knowledge, Certain Knowledge and Fixed Ability/Quick Learning.

The *sophisticated* belief Map 12 shows more positive correlations than negative correlations. Sophisticated epistemological beliefs, although not as closely associated with high cognitive outcomes as for SI students, similarly tend to provide a link between high cognitive outcomes and more positive assessment of the learning environment. A more sophisticated belief in Fixed Ability/Quick Learning is associated with more positive rating of the learning environment, particularly Teacher Interpersonal Qualities.

Procrustes analysis

The Procrustes statistic for the comparison of SI and TI *naïve* EB, *Actual* LE maps (9 and 11) is 0.46, corresponding to an average (RMS) distance of 1.1 units. The Procrustes statistic for the comparison between SI and TI *sophisticated* EB, *Actual* LE maps is 0.43, corresponding to a (RMS) distance of 1.0 units. See Table 5.1. These data show that SI students view their learning environment quite differently from TI students. In addition, the differences between SI and TI maps are constant, regardless of whether presented as *naïve* epistemological belief orientation or *sophisticated* belief orientation.

The SI maps, however, are more spread along the x-axis and the TI maps are more spread over the x-y plane. This is supported by the stress versus dimensionality graphs (Figure 5.2B), which show that the SI solution could almost be one-dimensional whereas the TI solution requires at least two dimensions.

5.7.2 Summary of observations and conclusions from Maps 9-12

The following conclusions (Table 5.3) are drawn in relation to SI students' interrelationships between their *Actual* learning environment, epistemological beliefs, IT self-efficacy beliefs and cognitive outcomes (in comparison with TI students').

Table 5.3 Observations and conclusions for SI students' interrelationships between *Actual* learning environment, epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs.

Observations	**Conclusions**
Wide separation between Cognitive Outcomes and Learning Environment regions. [Less wide for TI students.]	SI (and TI) students with lower results (marks) appreciate to a greater extent the constructivist nature of their LE. This is more evident with SI students.
Three-way separation of naïve epistemological beliefs (SK and FA/QL), cognitive outcomes and learning environment regions. [Wider for TI students.]	Students with more naïve beliefs have lower cognitive outcomes and lower rating of the learning environment.[a] (see comment on following page)
Teacher Interpersonal Qualities parameters located a greater distance from Cognitive Outcomes than the Student Communication and Reflection parameters – both groups.	Student Communication and Reflection parameters are more closely linked to cognitive outcomes than are Teacher Interpersonal Qualities.
SI students with more sophisticated belief in SK and FA/QL rate the Learning Environment more constructivist. (For TI students only FA/QL)	Students who believe in the complexity of knowledge and the developmental nature of ability and learning appreciate to a greater extent the constructivist nature of the LE. This is more evident with SI students.
SI students with more naïve belief in Expert Authority rate the Learning Environment more constructivist.	Students who believe that knowledge is gained from experts appreciate to a greater extent the constructivist nature of the LE. This is more evident with SI students.
SI students associate Support with Empathy rather than with Leadership.	SI students view their teachers as empathetic collaborators. TI students view teachers as supportive directors.

[a] This suggests that SI students associate lower marks with teachers' behaviours. This may reflect a disenchantment of students who do not learn physics as well as they want or the way they want to learn. Naïve beliefs about knowledge mean that students do not learn appropriately and they perceive this as being related to the behaviours of the teachers. Their beliefs about knowledge do not allow them to conceive of their learning difficulty being related to 'learning' as much as to 'teaching'. Because teaching is not perceived as being under their control, students might well exhibit a sense of helplessness about their situation

SI students' maps of their *Preferred* learning environment and comparison with their *Actual* learning environment.

Figures 5.18A and 5.18B (Maps 13A & B): Correlations among **SI** students' *naive* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Preferred* learning environment assessments.

Figures 5.19A and 5.19B (Maps 14A & B): Correlations among **SI** students' *sophisticated* epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Preferred* learning environment assessments.

NB. Maps 13 and 14 are alternative representations of the same data. For map 14, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

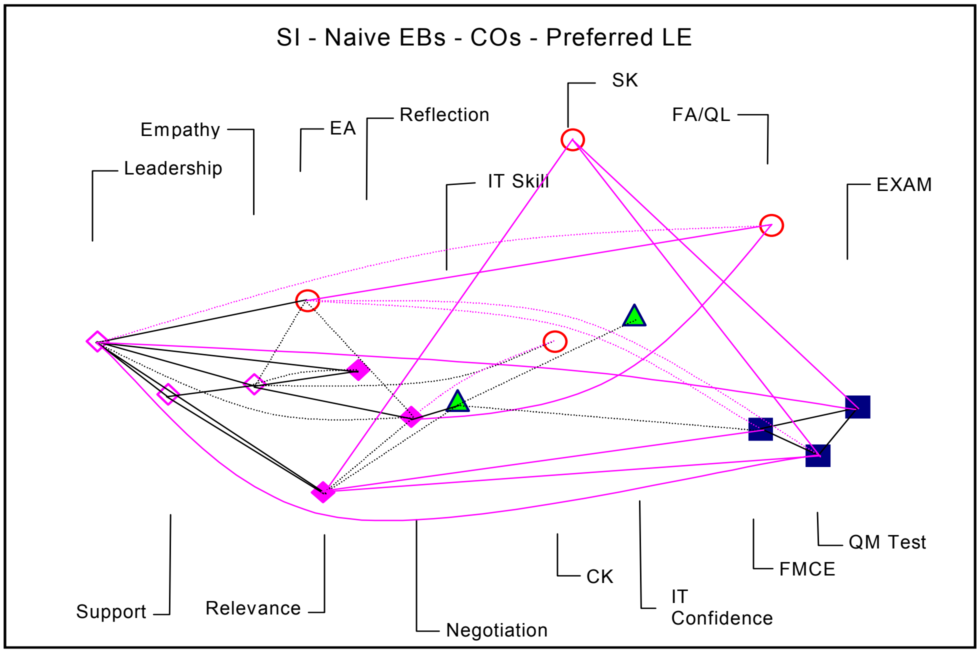

*Figure 5.18A. Map 13A – showing **correlations** among SI students' 'naive' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

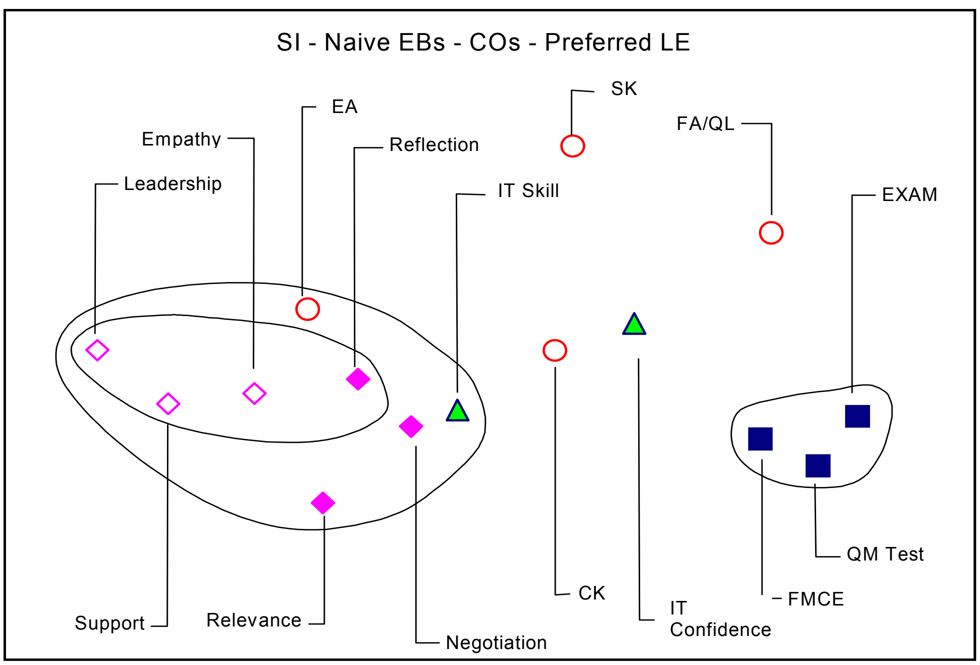

*Figure 5.18B. Map 13B – showing regions of association and **interrelationships** between SI students' 'sophisticated' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

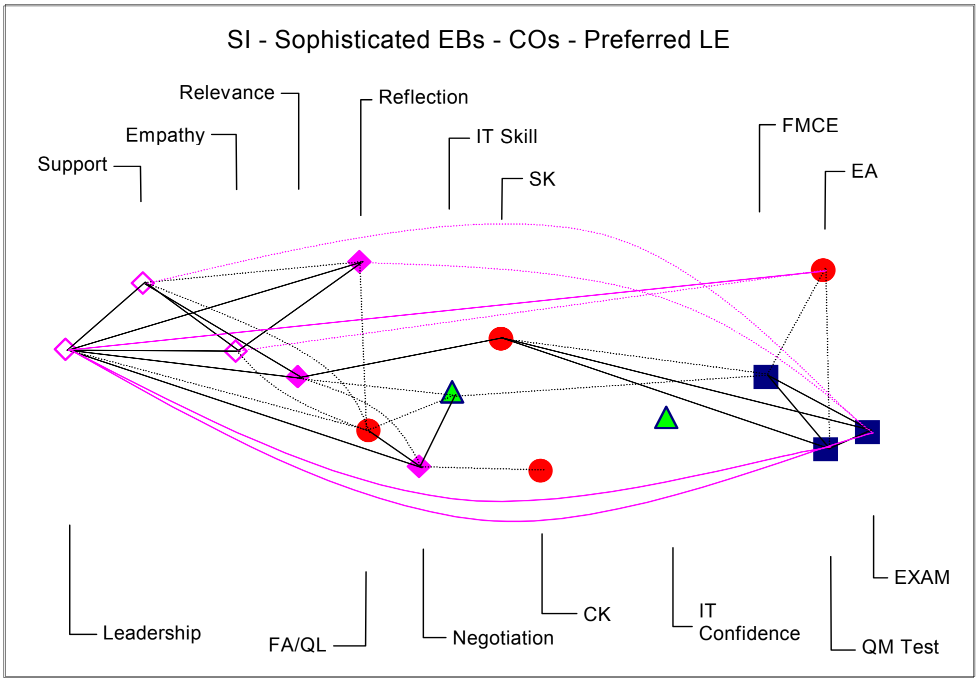

Figure 5.19A. Map 14A – showing ***correlations*** *among SI students' 'sophisticated' epistemological beliefs, assessments of the Preferred LE and cognitive outcomes.*

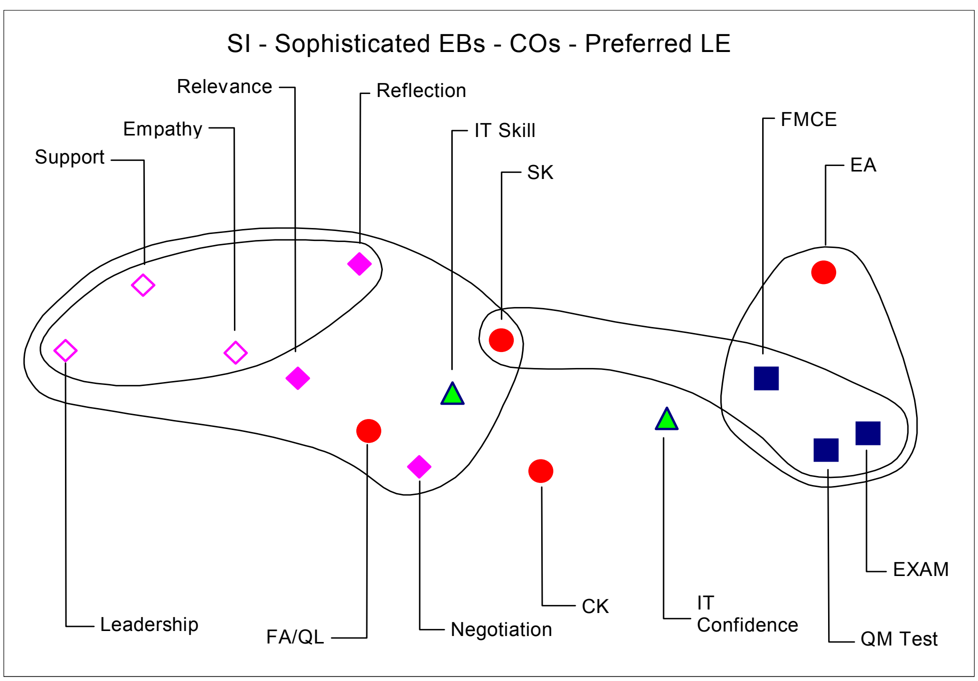

Figure 5.19B. Map 14B – showing regions of association and ***interrelationships*** *between SI students' 'sophisticated' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

Interpretation of maps 13 and 14

These maps use the same data as Maps 5 and 6 with *Preferred* learning environment data added. Hence, there should be a visual similarity between the *naïve* epistemological belief maps (13 and 5) and the sophisticated epistemological belief maps (14 and 6). Note also that Maps 13 and 14 should show similar configurations for cognitive outcomes, IT self-efficacy beliefs and learning environment assessments. The difference between the two is the location of epistemological beliefs, with map 13 showing *naïve* epistemological beliefs as the high score and map 14 showing *sophisticated* epistemological beliefs as the high score. Hence, all conclusions drawn from analyses of Maps 5 and 6 are applicable here.

SI students' *Preferred* learning environment is marked by a close interrelationship among all six learning environment variables. The Teacher Interpersonal Qualities scales are the most closely related (although not quite as densely grouped) and nested within a region containing the Student Communication and Reflection scales. SI students are *consistent* in how 'constructivist' they would prefer the learning environment to be. Students who prefer a highly 'constructivist' environment for any given scale are likely to rate the other five scales similarly. A similar conclusion can be drawn for students who prefer a less 'constructivist' learning environment.

There is a close association between preference for Reflection (reflective learning behaviour) and the three Teacher Interpersonal Qualities scales. This represents a large difference between the *Actual* and *Preferred* learning environments. In the *Actual* learning environment, Reflection is more closely linked to cognitive outcomes.

There are still significant negative correlations between the cognitive outcome variables and learning environment scales. SI students with higher cognitive outcomes rate their preference for Support, Empathy and Leadership lower than students with lower cognitive outcomes.

SI students with more naïve epistemological beliefs in Simple Knowledge and Fixed Ability/Quick Learning tend to have both lower cognitive outcomes **and** to prefer a less 'constructivist' learning environment than students with more sophisticated beliefs. Students with more naïve belief in Expert Authority would clearly prefer a more 'constructivist' learning environment. Such students want more Support, Leadership and Empathy from teachers and more opportunities for Reflection on knowledge.

The 'sophisticated beliefs' map is once again richer, with more positive associations and overlapping, connective regions. Students are not so divided in their views and opinions.

TI students' maps of their *Preferred* learning environment and comparison with their *Actual* learning environment.

Figures 5.20A and 5.20B (Maps 15A & B): Correlations among TI students' naive epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Preferred* learning environment assessments.

Figures 5.21A and 5.21B (Maps 16A & B): TI students' sophisticated epistemological beliefs (final), IT self-efficacy beliefs (final), cognitive outcomes (final) and *Preferred* learning environment assessments.

NB. Maps 15 and 16 are alternative representations of the same data. For map 16, the correlations between epistemological beliefs and all variables (but themselves) have been reversed in sign.

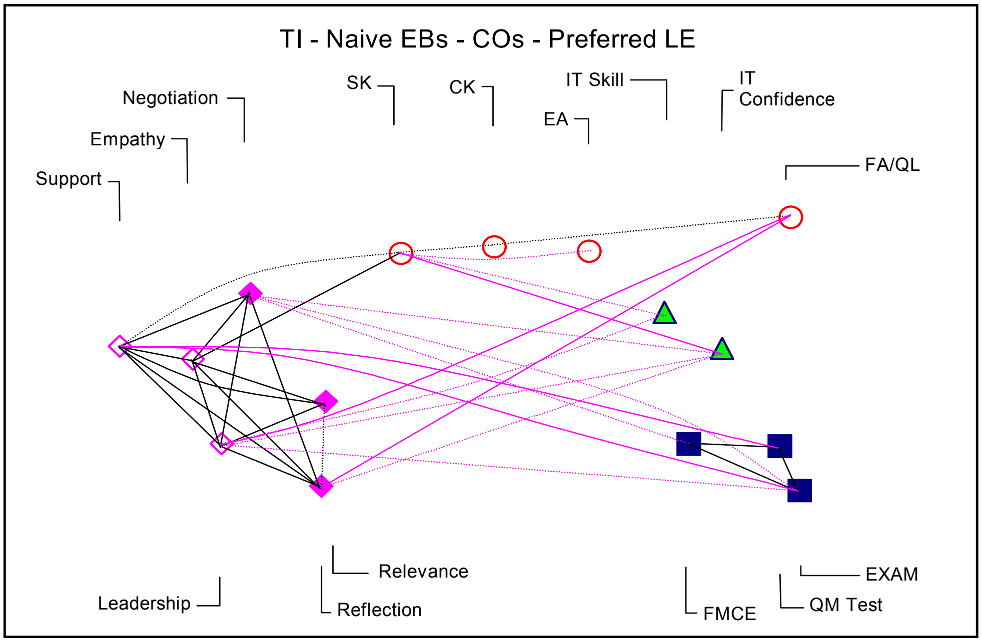

Figure 5.20A. Map 15A – showing ***correlations*** *among TI students' 'naive' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

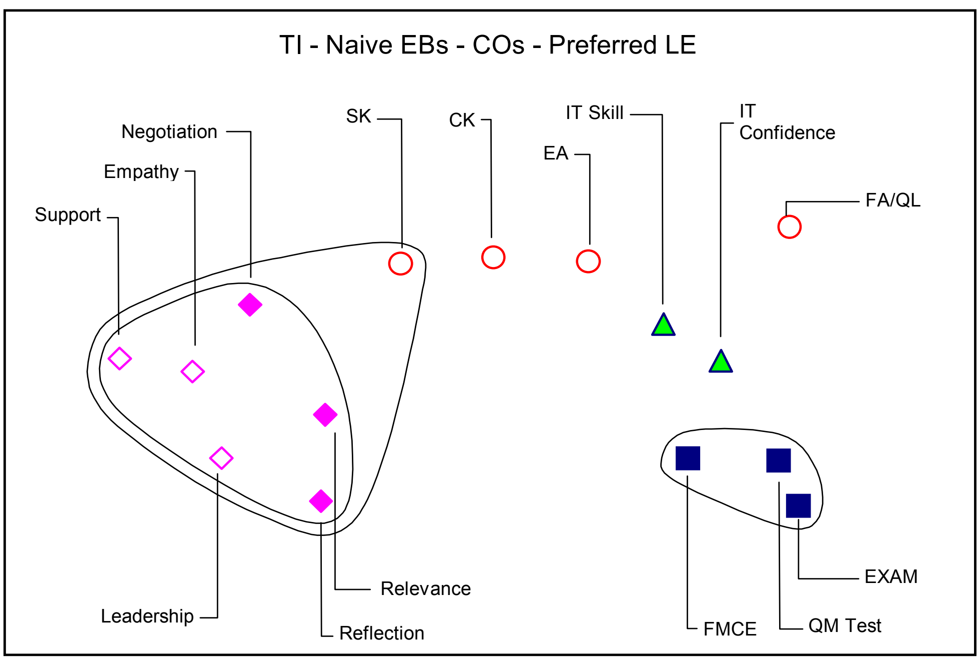

Figure 5.20B. Map 15B – showing regions of association and ***interrelationships*** *between TI students' 'naïve' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

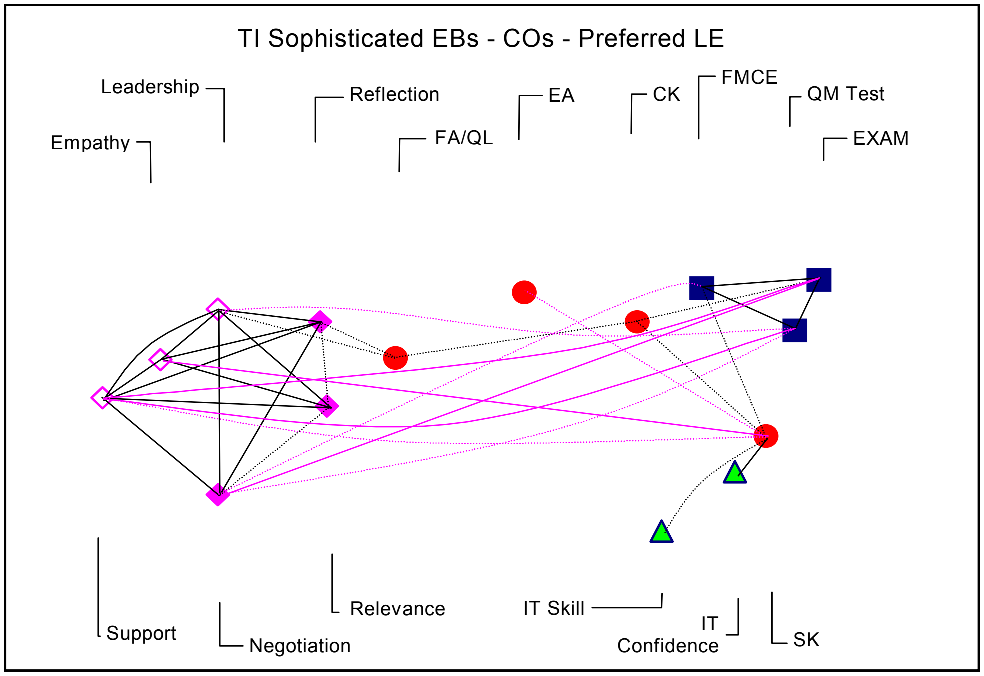

*Figure 5.21A. Map 16A – showing **correlations** among TI students' 'sophisticated' epistemological beliefs, assessments of the Preferred LE and cognitive outcomes.*

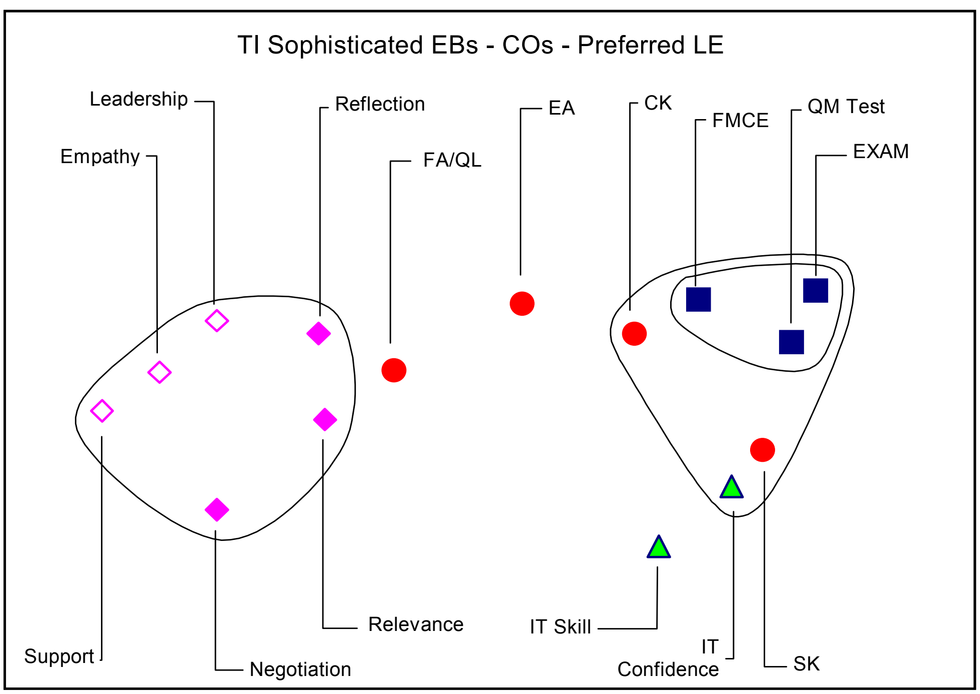

*Figure 5.21B. Map 16B – showing regions of association and **interrelationships** between TI students' 'sophisticated' epistemological beliefs, assessments of their Preferred LE and cognitive outcomes.*

Interpretation of maps 15 and 16

These maps use the same data as Maps 7 and 8 with *Preferred* learning environment data added. Hence, there should be a visual similarity between the *naïve* epistemological belief maps (15 and 7) and the *sophisticated* epistemological belief maps (16 and 8). Note also that Maps 15 and 16 should show similar configurations for cognitive outcomes, IT self-efficacy beliefs and learning environment assessments. The difference between the two is the location of epistemological beliefs, with map 15 showing *naïve* epistemological beliefs as the high score and map 16 showing *sophisticated* epistemological beliefs as the high score. Hence, all conclusions drawn from analyses of Maps 7 and 8 are applicable here.

The *Preferred* learning environment of TI students appears to be less complex than that of SI students. Overall, the two TI *Preferred* maps (naïve and sophisticated) are less complex than the *Actual* maps.

The six learning environment variables are all inter-correlated but without the nested structure of Teacher Interpersonal Qualities. Students with higher cognitive outcomes tend to prefer a less 'constructivist' learning environment while those with lower cognitive outcomes tend to prefer a more 'constructivist' learning environment.

The only association at all between epistemological beliefs and learning environment scales is a naïve belief in Simple Knowledge, which is weakly associated. One might offer a tentative explanation that students who view knowledge as discrete and unambiguous facts might prefer a situation in which they are helped to learn this way. Despite the high degree of inter-correlation among learning environment scales TI students do not appear to base their learning environment preferences on any other of the variables measured in this study.

Procrustes analysis

Data in Table 5.1 shows that there is a greater similarity between the *Actual* and *Preferred* LE maps for SI students (Procrustes Statistic = 0.09 and 0.13) than for TI students (PS = 0.20 and 0.42). SI students' *Preferred* learning environment is thus more closely matched to their *Actual* learning environment than TI students'. This data supports the inferences made in Chapter 4. In this analysis, however, we are examining the extent to which students are consistent in the way they judge their learning environment to be and how they would prefer it to be. This data shows that for SI students, there is a similar *pattern* of student opinions that is preserved from *Actual* to *Preferred* judgements. TI students are less consistent in their pattern of opinions.

5.7.3 Summary of observations and conclusions from Maps 13-16

The following conclusions (Table 5.4) are drawn in relation to SI students' interrelationships between *Preferred* learning environment, epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs (in comparison with TI students').

Table 5.4. Observations and conclusions for SI and TI students' *Preferred* learning environment, epistemological beliefs, cognitive outcomes and IT self-efficacy beliefs in comparison with the *Actual* learning environments.

Observations	Conclusions
SI *Preferred* LE is more complex than the TI *Preferred* LE.	There is a complex web of supportive interrelationships between the variables defining the *Preferred* learning environment of SI students.
SI *Preferred* map has nested LE region with closer links to epistemological beliefs. TI has single LE region unrelated to any epistemological beliefs.	SI students have a greater appreciation of the meaning of a 'constructivist' LE that is not as evident in TI students. Teacher Interpersonal Qualities are central to the learning environment. SI students who prefer a more 'constructivist' LE tend to have more naïve belief in Expert Authority and more sophisticated belief in Simple Knowledge and Fixed Ability/Quick Learning.

There is a greater degree of similarity between *Actual* and *Preferred* learning environments for SI students compared with TI students.	SI students are, in general, more satisfied with their LE in that they prefer a LE that is much the same as what they believe they are experiencing. TI students would prefer a less complex learning environment.

5.7.4 Learning preferences in MDS maps

During this study, I also investigated the interrelationships among students' epistemological beliefs, cognitive outcomes and physics learning preferences using MDS. Details of this analysis and the resulting MDS maps are not reproduced here. Instead, an article that I have submitted to an international journal for publication has been included as Appendix A.3.2.

5.8 Discussion

This chapter has been about portraying two learning environments in a visual way such that comparisons or inferences can be made from the patterns within them. The fourth research question related to ascertaining if the technique could be used to differentiate between the learning environments. The technique I have adopted is to assume that the TI learning environment is the norm (or control) and that the SI learning environment is either similar to or different from it.

MDS maps are easily produced from correlational data. Identification of meaningful regions is accomplished by reference to the original data (correlation coefficients) and supported by cluster analysis. Interpretation of maps, however, is not simple, and may render the technique unworkable in a practical sense.

One problem is the interpretation of a map based on correlations rather than just on similarities or differences. Another is the incorporation of a 'double-ended' scale rather than an absolute scale in a MDS map. A correlation scale runs from –1 to +1. In some cases the data might range only from 0 to +1. Either way, appropriate meaning must be extracted from the configuration and identified regions. A map containing several groupings or nested regions does not necessarily indicate the existence of negative correlations. A decision was made here to identify regions with two or more negatively inter-correlated variables as closed, non-overlapping regions. Where there are no negative correlations, overlapping or nested regions are the most likely ways of grouping variables.

The incorporation of epistemological beliefs continua into MDS maps presents a unique problem. In this work, I have chosen to present both 'naïve' and 'sophisticated' representations even though they both carry essentially the same meaning. I suggest, however, that for ease of interpretation, one of these only be displayed in published works. The easier one to interpret is the one in which 'sophisticated' beliefs are given the high score. This contradicts Schommer (and others) who use 'naïve' as the high score since the object of interest is the naïve belief rather than the sophisticated belief.

In this study, there were obviously different configurations or patterns that differentiated the SI learning environment from the TI learning environment. To a 'trained eye' the information conveyed in the maps is potentially more rich and complex than that obtained in earlier analyses of data. The information or inferences gained from the maps fall into two categories:

1. Ideas that agree with or confirm earlier findings (from the comparative study – Chapter 4), and
2. Ideas that add to or elaborate on earlier findings.

There are also ideas that these maps do not reveal. They cannot provide information on absolute differences between groups, such as differences in cognitive outcomes or epistemological beliefs.

The majority of findings fall into category 1 (above). These will not be re-stated. Instead, the more interesting category 2 ideas will be presented.

Category 2: Reflective Thinking (reflection) was an issue in the earlier analysis of learning environment data. There was no difference between groups on *Actual* scores and both groups expressed a desire for more opportunities for reflective thinking. An analysis of SI students' SMARFs indicated that they had little concept of what this might mean. The Maps however, reveal a little more about this issue. In the *Actual* learning environment maps, Reflective Thinking is central for TI students and closer to the cognitive outcomes region for SI students. SI students with higher cognitive outcomes tend to perceive more opportunities for reflection *actually* existing. In the *Preferred* learning environment maps, Reflection has migrated to the learning environment regions, in particular, close to the Teacher Interpersonal Qualities sub-region for SI students. Thus, it is the students who want a more constructivist learning environment, who also want more opportunities for Reflective Thinking.

Inferring additional information from maps may also result in invalid conclusions. One concern is that of drawing inferences, for example, about the migration of variables from one part of a map to another and not having a way of quantitatively establishing whether the movement is, or is not, meaningful. Similarly, in comparing the location of a single variable in two different maps, there is the chance of inferring a difference when, in fact, no difference exists. I have concluded that the *Preferred* learning environment of SI students is much richer and with more interrelationships among variables than the *Preferred* learning environment of TI students, based on the differences in pattern complexity. There is only limited evidence from the data in this study to support such an assertion.

There appears to be only one paradoxical situation. A feature of the learning environment maps of both groups is the location of Teacher Interpersonal Qualities (TIQ) group on the extremity of each map, indicating that students with high cognitive outcomes rate teacher interpersonal qualities lower than those with low cognitive outcomes. Student Communication and Reflection (SCR), however, is more closely linked to cognitive outcomes. Despite this, both groups rate the TIQ parameters (support, leadership and empathy) more highly than the SCR parameters (Relevance, reflective thinking and negotiation). This is not an anomaly in the data but the result of using different statistics. The maps illustrate correlations between scores on tests and ratings of the learning environment. There is no relationship between mean scores and correlation between two sets of data. What the data does show is that although students with lower outcomes rate the TIQ parameters highly, it is the SCR parameters that are more closely related to cognitive outcomes.

5.8.1 Overview of the MDS methodology - validity and reliability

These MDS solutions and interpretations are, metaphorically speaking, a long way from the original data. The questionnaire data have been manipulated to obtain belief and attitude scores. Correlation coefficients have been determined for all relevant variables, and MDS solutions of optimum dimensionality produced. These maps have then been divided into regions and finally interpreted. Therefore, the greatest concern is that mounting uncertainties and errors will render the final maps meaningless. In defence of this, there are no significant inconsistencies within any of the maps.

Reliability

MDS is a data reduction technique not unlike factor analysis or cluster analysis. The difference is that the output is a spatial representation rather than a series of scores or numbers. This makes it more difficult to argue for reliability of the process or validity of the results or conclusions.

The main evidence for the reliability of the process – starting with the correlation matrices, is that all solutions have sound goodness-of-fit statistics and plausible configurations. As well, different representations of the same data have produced maps that are very similar. When epistemological belief variables were reversed in sign, the configuration of other points remained essentially unchanged. When the learning environment variables were added, the positions of all other points mapped in explainable positions. Small changes are to be expected because each point does not have a totally unique position. Hence the production of 'sophisticated' and 'naïve' maps was the best way of testing pattern stability.

Finally, the reliability of these maps rests on the consistency of measurement of the original data. A weakness in this study is that although 'matched' groups were selected for comparison, not all data was available for all students. Where initial and final comparisons have been made, only students whose initial and final data were available have been included. However, in the construction of MDS maps, correlations among variables used as many students' data as was available. Hence, from a group of 70 TI students, the correlations have been for between 56 and 70 students – with most over 60. From a group of 45 SI students, the correlations have been for between 32 and 45 students – with most over 40. All correlation data is provided in Appendix A.2.2, Tables A.1 to A.8. This issue has also been covered in Chapter 4.

Validity

Validity refers to the extent to which an empirical indicant measures what it purports to measure… … it is not the indicant itself that is being validated but … the purpose for which the indicant is being used that is submitted to the validation process

(Zeller, 1988, p. 323)

From this definition of validity, I am inferring that the process of validation involves examining the match between the maps, how one might visually interpret them and the subsequent conclusions that might be drawn from them.

The comparative data between SI and TI students indicated very little difference between the groups in cognitive outcomes (except conceptual understanding), only small differences between them in epistemological beliefs (Simple Knowledge and Certain Knowledge) but large differences in assessments of their learning environments. However, these maps represent correlations, not means and standard deviations and hence they might tell a story that is different from that of the comparative data. On the other hand, they should not be *inconsistent* with the comparative data. *Any* inconsistency would be sufficient reason to question the validity of the maps.

The validity of the maps could be tested in several ways. How easy are the maps to interpret? How 'obvious' are the interpretations? Are the interpretations made the only ones possible or are there feasible alternatives? Are the interpretations consistent with other data?

Correlations as proximities produce configurations that are not as easily interpreted as more straightforward similarity or dissimilarity data. It would be easy for a casual observer to infer likenesses or dissimilarity between variables rather than closeness in association or degree of negative or opposite association from the juxtaposition of points or regions.

A 'double-ended' scale such as the epistemological belief scale introduces another level of complexity that I have not seen before. It leads to the production of two maps, depending on which ‘end’ of the scale is given the higher score. This has added to the richness of interpretations that can be made from the data, but it might also be a source of confusion or misinterpretation for the casual observer.

The maps are consistent with the comparative data in that there are more similarities between the SI and TI groups than there are differences. Given that the students are all first year university students studying physics and intent on a career in a scientific or engineering discipline, one might expect a high degree of commonality despite individual differences. Many of the differences between maps are explainable in terms of the different learning environment experiences of the two groups.

Making systemic comparisons between students’ learning environments, as I have done, is not a well-publicised use of MDS. I have used the technique in an exploratory as much as expository way. Hence, in addition to summarising what I have learnt about SI and TI students’ portrayals of their learning environments, I am able to comment on the usefulness of the technique for the purpose for which I have used it.

In this study, the Procrustes analyses were most useful when comparing two configurations of the same group of students, not when comparing one group with the other. A quantitative comparison between *Actual* and *Preferred* learning environment maps for the TI and ST groups gave a meaningful indication of the degree of difference that each group exhibited.

5.9 Review of Chapter 5

In this chapter, I have investigated the use of multidimensional scaling as a way of producing visual representations of a learning environment, and whether or not MDS maps can be used to compare two different learning environments. The technique has been used to reduce complex data and interrelationships to a visually interpretable form. The results suggest that meaningful maps can, indeed, be obtained and that they can be used to distinguish between the structure and characteristics of the two groups. The maps are relatively easy to produce, but may not be easy for a casual observer to interpret.

5.10 References for Chapter 5

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CHAPTER 6: SUMMARY AND CONCLUSIONS

In this chapter, I give an overview of the study in relation to the four main research questions listed in Chapter 1 and justify the research methods that I have used. I summarise the main findings before discussing the significant issues and recommendations emerging from the research. Finally, constraints, limitations and directions for future research are presented.

6.1 Overview of study

Lecturing continues to be the favoured method of physics course ‘delivery’ in Australian universities. However, extensive research has demonstrated that lectures are largely ineffective in changing physics students’ basic conceptual knowledge structures (Champagne, Gunstone, & Klopfer, 1985; Hake, 1998; Redish, 1996). Recent research would suggest that constructivism offers an alternative and apparently fruitful way of understanding how students learn conceptually difficult material such as physics (Cobern, 1993; Gunstone, 1992; Scott, Asoko, & Driver, 1991). Although lecturing per se does not imply only a transmissionist view of teaching, a lecture approach makes it harder to employ constructivist strategies that emphasise the individual’s role in the construction of knowledge.

In 1992, faculty at Rensselaer Polytechnic Institute introduced a Studio approach as an alternative to lectures. Computer-based technology and software were developed to facilitate the ‘content delivery’ normally accomplished by lecturers. Lectures, practical sessions and tutorials were combined into multipurpose sessions. Teachers and tutors were able to move among students offering more attention to individuals or groups of students. However, Studio classes did not result in any better conceptual learning than did traditional lecturing approaches, and well short of the learning occurring in physics classes adopting a variety of researched interactive engagement methods (Cooper, 1995; Cummings, Marx, Thornton, & Kuhl, 1999).

The Curtin Physics Studio was thus designed to accommodate interactive engagement teaching strategies within a technology-rich Studio learning environment. In addition, strategies consonant with a social constructivist approach to education, and in which learners are encouraged to become more metacognitively aware and eventually take control of their own learning, are also employed.

In this study, I investigated the extent to which the knowledge and beliefs of physics students changed as a result of a year of Studio experience by comparing them with a matched group of students in an equivalent, lectured-based physics course. As part of this, I examined the interrelationships of students' epistemological beliefs, perceptions of the Studio learning environment and students' cognitive outcomes, i.e. their physics learning.

Research on epistemological beliefs is relatively new and not without some controversy and scepticism. Epistemological beliefs are not a well-defined construct, nor is their measurement easily accomplished. In defence for pursuing this line of research, I draw on the following statement from Zare (1996, p. 7):

> *We must not let a cycle be created in which the need for accountability leads to the use of measurement standards, which leads to polishing existing paradigms, which leads to further demands for accountability and so on …Put another way, we must avoid 'looking for the lost key where the light is brightest'. We must avoid allowing what can be measured to become what matters, rather than seeking to measure what matters, which frequently are attributes that cannot be measured.*

Learning environment research by questionnaire and qualitative research methods is an established activity. The representation of learning environments using multidimensional scaling (MDS) has been proposed more recently as a vehicle for investigating systemic patterns and change, in particular where diverse and complex data are involved. MDS techniques that use correlation coefficients among various learning environment parameters to represent similarities raise some issues associated with the ease of interpretation of the resulting configurations.

The methodology adopted in the study examined the learning environment and student learning from the point of view of the whole Studio group and also individuals within it. The emphasis has not been 'How better is one group than another?' but rather, 'How different is one group from another as a result of their different learning experiences?' The Ex Post Facto causal-comparative evaluative design (Crowl, 1989) has been complemented with correlational, survey and participant observer methods. Results have been primarily analysed using a statistical approach. The study has also incorporated an investigation of the technique of reducing complex data using multidimensional scaling. The correlational data has been re-analysed using MDS in an attempt to characterise different learning environments in visual spatial representations.

6.2 Summary of findings and recommendations for educational practice

I will summarise the main findings of this study under the four research objectives and then outline several themes that have developed.

6.2.1 What are the cognitive outcomes of students learning physics in the Studio course?

The only way this can be reported is (a) in relation to the Traditional Instruction group of students and (b) in relation to other reported statistical results. There can be no absolute standard.

There is evidence that the Studio course afforded students an advantage in learning outcomes over that of students in the Traditional course. SI students' results in the Semester 1 examination were higher, the change in their Newtonian conceptual understandings was greater and they reported a greater improvement in their perceived computer-related skills. Other measured learning outcomes were statistically equivalent for both groups.

The change in SI students' Newtonian conceptions was comparable with that of students in Rensselaer Polytechnic Institute's 'experimental' Studio classes, and the change in TI students' Newtonian conceptions was less, being comparable with that of students in RPI 'traditional' Studio classes. See Cummings et al (1999).

Considering that there were learning advantages for students in the Studio, these advantages were not adequately reflected in their formal results. While greater conceptual knowledge/understanding improvement may have been one reason for SI students' better examination results, there is no explicit or formal recognition of, or for, the students who have undergone such change.

The traditional mode of assessment by formal examination and tests, mostly multiple-choice in nature, where all questions are portrayed as having 'right' answers, continues to be the way that we customarily assess students' knowledge of the subject. More importantly, such assessments most likely serve to support students' beliefs in 'absolute knowledge'. It is, perhaps, a failing of the Curtin Studio approach that in adopting a social constructivist mode of instruction, we have not, at the same time, adopted a constructivist model of assessment. According to von Glasersfeld (1993), it is important to assess how students think or respond to problems, rather than merely measure the end result. Hendry (1996) supports this by proposing that the goal of learning may be undermined (for students as well as for teachers) if there is undue emphasis on reward for students to get 'correct' answers instead of a focus on the process of developing knowledge. Thus in the Studio, if the goal of learning physics is a priority, then the *process* of learning must also be rewarded, and seen to be rewarded.

Possible assessment strategies that could be employed to support the development of more sophisticated epistemological beliefs are those supported by constructivist educational practice. Production of a reflective portfolio or at least a journal would encourage students to be the judge of their own learning rather than expect this to be solely the role of the teacher or unknown examiners. The extent to which students can do this without some learning and guidance is unknown. If students are to value such an exercise, there must initially be some worth (e.g. marks) attached to it. With time, they may develop an intrinsic value for the process of self-evaluation.

Students should also be encouraged to explore and to represent their knowledge in a variety of ways or formats as an alternative to rigid problem-solving exercises. Some freedom to investigate their own areas of interest, within agreed boundaries, and to present their findings in a variety of ways, oral, written, pictorial or using technology, would support views about the complexity and interrelatedness of different areas of physics.

Studio students, through their self-efficacy beliefs, report that they have developed better computing skills. Learning to use computers for the purposes of communication (e.g. email), learning and using statistical or graphical analysis software (e.g. MS Excel), and learning to use software or internet sites for learning physics, occupy a considerable part of the time that students are in class, and yet they are skills or processes that also go unrecognised and unrewarded in the Studio programme. This may be a reason why SI students, like TI students, do not report any increase in their confidence in or value for using computers for learning.

The equal pass rates for the whole Studio and Traditional courses over the year served to mask a lower fail rate but greater dropout rate from the Studio course in Semester 1. Reasons for this should be investigated and the problem(s) resolved since one of the objectives of the Studio programme was to improve student retention rates.

6.2.2 How do these Studio students assess and respond to the social constructivist nature of their learning environment?

SI students give a high rating to the social constructivist nature of the Studio learning environment and clearly recognise that it is different from a traditional learning environment. The average on all six scales of the University Social Constructivist Learning Environment Survey (USCLES), Relevance, Reflective Thinking, Negotiation, Leadership, Empathy and Support, was approximately 4.0 whereas the average rating for TI students was approximately 3.0. In addition, both groups indicated that would prefer a greater frequency of social constructivist practice.

SI students are more satisfied with their learning environment than are TI students. This conclusion is supported by data from the USCLES and by the MDS ‘maps’. Firstly, there is a narrower gap between Actual and Preferred scores for the SI group compared with the TI group – the mean difference is about 0.5 of a scale unit for the SI group and about 1.0 scale unit for the TI group. Secondly, evidence from the learning environment maps is that there is a greater degree of similarity between the Actual and Preferred maps for SI students than there is for TI students. Hence, although both groups would prefer more frequent constructivist practices, the interrelationships between variables are more similar in nature for SI students, as evidenced by the greater similarity in map structures.

Although TI students say they would prefer a greater frequency of social constructivist practices, at the same time, they want a simpler or less complex learning environment. This is evident in the Preferred learning environment maps, which show a three-way separation of constructivist learning environment parameters, epistemological beliefs and learning outcomes. SI students, on the other hand, would prefer a more complex relationship between constructivist learning environment parameters, epistemological beliefs and learning outcomes. This lends support to Salomon's (1996) finding that a Technology Enhanced Learning Environment was marked by a close relationship between social interaction and student learning.

Although SI students 'like' their learning environment, many do not know how best to take full advantage of it. The role of reflective thinking in the learning process remains problematic for SI students. Students want more such opportunities but the purpose of reflective thinking remains unclear to them. They are heavily reliant on 'doing assignments' as a way of learning, although there is some evidence that other ways of learning have some validity for SI students. A recommendation is that SI students be given more assistance to develop metacognitive skills and that more overt recognition be given to those who reconceptualize their less effective ways of learning.

6.2.3 What is the nature of the interrelationships between students' perceptions of the learning environment, epistemological beliefs and cognitive outcomes?

It is reasonable to assume that students' beliefs and attitudes about knowledge and learning influence how they perceive the characteristics of their learning environment, their preference for certain physics learning behaviours and their cognitive outcomes. The interest is which epistemological beliefs predispose students to respond to the learning environment in certain ways or learn in certain ways? The issue also is whether sophisticated epistemological beliefs are associated with:

- high or low ratings of a social constructivist learning environment;

- traditional or non-traditional preferred learning strategies; and
- high or low cognitive outcomes.

To this end, four themes have emerged:

Epistemological beliefs in general

Where there is a relationship between epistemological beliefs, perceptions of the learning environment or cognitive outcomes, in almost every instance naïve belief is associated with the perception of fewer instances of social constructivist teaching and learning behaviours and with lower cognitive outcomes. The relationships tend to be stronger for SI students than for TI students. Thus, for SI students at least, more sophisticated beliefs appear to be more favourable for learning physics.

There also appears to be a dichotomy of epistemological beliefs into those reflecting the structure and certainty of knowledge (Simple Knowledge and Certain Knowledge) and those reflecting the source of knowledge and learning (Expert Authority and Fixed Ability/Quick Learning). Belief in Simple Knowledge and Certain Knowledge are more likely to be related to preferences for particular learning behaviours and cognitive outcomes. Belief in Fixed Ability/Quick Learning and Expert Authority, on the other hand, are more likely to be related to students' rating of the learning environment and their beliefs about the role of teachers.

Belief in Simple Knowledge

The epistemological belief factor that appears to play the most significant role in students' physics learning is belief in Simple Knowledge. Students who believe that knowledge is composed of isolated and discrete facts prefer a narrow range of learning activities that mirror class work and also have poorer learning outcomes, regardless of mode of instruction. Students who view knowledge as a complex net of interrelationships favour a wider range of learning activities and also have higher cognitive outcomes. Schommer et al (1997) found a similar result and suggested that the link between belief in Simple Knowledge and cognitive outcomes would be through students' preferred ways of learning (see Chapter 2). Thus a more sophisticated belief in Simple Knowledge appears favourable in physics learning, regardless of mode of instruction.

An initial hypothesis in this study was that students immersed in a social constructivist learning environment would develop more sophisticated epistemological beliefs, and the epistemological beliefs of students immersed in a traditional neo-positivist learning environment would not change. However, the outcome was similar to that found by Redish et al (1998) using the Maryland Physics Expectation Survey – a deterioration of favourable beliefs/attitudes. Belief in Simple Knowledge deteriorated for both groups, only less so for the Studio group. It would appear that the nature of physics and how students perceive that it must be learned is a more dominant factor in shaping this belief.

Paulson and Wells' (1998) study that found students in 'hard' disciplines were more likely to hold naïve epistemological beliefs, might suggest that learning in physics is supported by naïve beliefs – that students who question authority, believe that physics knowledge is infallible and consists of discrete, unrelated facts would be more likely to succeed. This is not fully supported by this data. However, physics and engineering students are involved in a narrower range of similar, and probably 'hard' subjects than they were at school, thus reinforcing naïve beliefs about the structure of knowledge. It is likely that students' experiences in the Studio learning environment have moderated the effect of the subject matter and its assessment.

Role of teacher and authority

It is clear that a majority of students rely on, and expect to continue to rely on, their teachers and tutors for learning physics. Students expressed this in several ways, through their self-reflection and monitoring documents, through the higher rating on the Teacher Interpersonal Qualities scales of the USCLES assessment of the learning environment and through interviews.

SI students with more naïve beliefs in Expert Authority perceive, and also would prefer, a closer, more submissive and supported relationship with teachers – expressed as more Leadership, Negotiation and Empathy. Hence there is an understandable epistemological belief component to this expectation about teaching. These students also tend to have lower cognitive outcomes.

SI students with more naïve belief in Fixed Ability/Quick Learning (that ability is fixed and learning occurs quickly or not at all) perceive and would also prefer a more distant relationship with teachers. That is, students who believe that ability is fixed and learning occurs quickly or not at all, see no sense in closer relationship with teachers since this will not help students who ‘do not have the ability’ to learn physics. Bendixen et al (1994) found a similar result with high school students’ lack of perseverance with difficult tasks.

Physics knowledge and the task of physics

There is evidence that students have beliefs about physics and physics knowledge that affect how they learn. According to this study, physics is a hard subject made more difficult by ‘mathematics’. Hammer (1994) also found that high school physics students see mathematics as an obstacle to learning.

Students mostly associate physics with transmissionist teaching. The majority of students expect and depend on teachers to get them through the complexity of physics by explaining difficult ideas and by organising the learning to make the subject easier. This can be accomplished by giving them only what they need to learn and no more. There is little evidence that involvement in the Studio course has changed students’ attitudes in this regard.

Thus, students who embrace the complexity of physics knowledge, and who learn through their own acknowledged efforts using a wide variety of learning strategies, have better physics learning outcomes. Their Studio experiences, if not teaching them to view physics and learn physics this way, at least serve to validate these approaches. It is therefore worth continuing the Studio approach even though it may come at some cost, for example, a higher initial dropout rate.

There are, however, avenues for improvements to be made:

- Help for students to understand and appreciate their own role in learning and value for self-monitoring and reflective practices.
- The implementation of more authentic assessment processes that reflect both the learning process and learning outcomes.
- Use of intervention strategies to help students whose beliefs make it difficult for them to accommodate constructivist practices to come to value such alternative teaching/learning methods.

6.2.4 How can these complex interrelationships be made explicit or understandable?

Spatial configurations of learning environments constructed by multidimensional scaling using correlation coefficients as the variables were visually interesting and potentially useful. The maps of the Studio and Traditional Instruction learning environments were similar for students as they entered their courses (Maps 1-4) and changed to different structures by the end of the year (Maps 5-8). See Chapter 5. The changes were explainable in terms of the original data and were consistent with conclusions drawn from the more traditional statistical and interpretive data analysis.

The addition of the USCLES data made the maps more complex but also provided for richer interpretations. The Actual and Preferred learning environment maps were consistent with the earlier data analysis, and in some instances, provided some insight into the nature of learning environments that were not evident in the initial analysis.

The use of double-ended scales, such as epistemological beliefs, in MDS configurations provided a unique opportunity to examine the learning environment from two points of view, that of the more epistemologically naïve believer and that of the more epistemologically sophisticated believer. This has enabled richer interpretations of the learning situations, as though through the eyes of different participants, to be made. The disadvantage has been the potential complexity of interpretation, which could limit the use of MDS maps for this type of scale.

The decision to use two- or three-dimensional plots is also worth discussion. The association between variables in two-dimensional plots is as represented visually and should not need to be supplemented with reference to the data. However, the uncertainty in location of variables is greater. Three-dimensional plots reduce the location uncertainty, but separation in the third dimension is not evident visually and may lead an interpreter to assume an association when one does not exist. Thus there is the need to refer to the data to confirm the strength of relationships.

6.3 Limitations of the study

The ex-post facto design of the study carried with it some limitations. Although the SI and TI groups were matched as closely as possible, not all data was available for all students. This would have the effect of reducing the reliability of some assessments or variables. In addition, while groups were matched on specific variables, there may be other uncontrolled variables, such as motivation or goal orientation. If the two groups differed significantly in some of these variables, some conclusions may be equivocal.

6.3.1 Methodological design

Several assumptions made in this study may have been a threat to its validity. Firstly, the study needed to compare attributes of the SI group with a 'normal' or non-treatment population. This raised the question: What is the nature of the 'normal' student population? For comparative purposes the TI group was thus assumed to be the normal or non-treatment population. Secondly, how does one study a group and not change it through the mechanism of measurement. One can draw a parallel between this and the fundamental nature of physical measurement, where to 'see' a particle inevitably means making an irreversible change to its motion. Both of these aspects combined to make the methodological design of this study difficult.

The best option was an 'ex-post facto' design which meant studying the Studio and Traditional streams *in situ* and not changing what might otherwise happen to their participants, except where such changes could happen to both. Because there were disparate elements in both groups, the 'control' mechanism was to use data from a subset of both groups (matched groups) for comparison. Each subset, however, may not be representative of the population from which they were drawn.

Of some dispute, therefore, might be the extent to which the influences of the students not in either of the matched groups is extraordinary i.e. so different that this will have a varying influence from year to year on sub-group populations. I contend that this is unlikely to be a significant effect. Few students in the Studio stream were not included in the studied SI ‘matched group’ and thus the effect will be small. Approximately half of the students not in the TI matched group of the Traditional stream were from overseas, and while they form a significant component of the Traditional learning environment, I would expect this to have a constant rather than variable effect from one year to the next. The effect of the larger cohorts on the epistemological beliefs of students in the respective matched groups, if present, might also be expected to be constant from one year to the next. Thus a subgroup of the cohort should not be rendered extraordinary as a result of these influences. Thus I argue that it has been valid to study a matched subgroup from each of these two populations.

The question of possible differential motivation between physics majors and engineering majors is a more difficult issue to defend. The contention might be that first year students whose goal is a practical-based engineering vocation will approach their study of first year physics differently from students whose goal is a physics degree and a less predictable job. Firstly, this assumes that all engineering students, from the different disciplines of mechanical, electrical and chemical engineering, have the same motivational characteristics. They may have, but equally they may not. On the other hand there is likely to be a large range of motivations within the students in this group. Similarly, the SI group is not homogeneous, with physics, geophysics, science and engineering/physics double degree students. One might expect there to be a range of motivations within this group as well.

It could be argued that first year engineering majors are not inherently interested in physics. This may be a reasonable assumption for some students but not for all. Engineering is not studied at high school and so students’ expectations about the study of engineering will be mostly based on their prior experiences in physics classes. They may have chosen to study ‘engineering’ but their prior knowledge and experience of it would have been learnt mostly as *physics*. Thus physics, geophysics and engineering majors choose what must be, to them, just different fields of the same subject.

Motivation has previously been linked to sophisticated epistemological beliefs {Hofer (1994); Schutz, Pintrich & Young (1993), cited in (Hofer & Pintrich, 1997)}. If the model that I have proposed (see Figure 4.3) is viable, then some motivation results from, rather than causes, differences in epistemological beliefs. Hence, I have assumed that in this study, students' initial motivation does not have a differential impact on the beliefs of students in the different streams except where the differences are due to factors that are already included in the study e.g. epistemological beliefs.

6.3.2 Choice of assessment instruments

Multiple choice tests are the usual form of assessment instrument and it was a design of the study that the comparison involved forms of assessment that were *normally used* as well as an assessment that measured a different form of understanding i.e. conceptual understanding. This was the reason for choosing the FMCE and the TCE.

There seems little doubt that multiple-choice tests foster surface learning in some individuals. This effect should be constant for both SI and TI groups, except where the instructional methods or learning environment encourages students to transcend this tendency. Hence, even with multiple-choice tests, differential performance can be attributed to the effect of the learning environment.

The question might be whether such tests assess only 'trivial' knowledge or whether they assess meaningful skills and conceptual knowledge. Well-constructed items can effectively differentiate between the skills and abilities of students. The Semester 1 examination produced reliable results; the QM test less so, however, the close association between the two in all MDS maps suggests a degree of consistency in what they have measured.

It is possible that another type of test of students' knowledge, perhaps in written format, could have been devised. However, with more subjective marking would be the possibility of a less reliable instrument. I do, however, make the point that the customary forms of assessment (multiple choice tests) are likely to negate efforts to encourage students to adopt more sophisticated beliefs about knowledge and thus, deeper learning strategies. Hence, alternative forms of assessment that support more sophisticated epistemological beliefs should be investigated for both groups.

6.3.3 Transferability of results

The results of this study should not be extrapolated, without due consideration, to other learning environments, or even to other Studio learning environments. If, as Moos (1979) suggests, characteristics of the setting, subjects, teachers and students all constitute the learning environment, then where any one of these is different, the learning environment is different. There are, however, some results that are not necessarily dependent on the specific learning environment:

- Physics concept learning. The results support other research that shows conceptual change in physics is not easily accomplished in a lecture situation.
- Role of epistemological beliefs in influencing learning behaviours. Naïve beliefs are associated with less productive learning behaviours.
- Students expect to be heavily reliant on the teacher for physics learning. They expect the teacher to make a difficult subject (physics) easy to learn.
- Constructivist teaching in ‘hard’ disciplines. The results of this study show that constructivist teaching strategies *can* be employed in a subject that is popularly underpinned by positivist philosophy.

6.3.4 Role of the researcher

The intimate involvement of the researcher as a tutor within the learning environment must be made explicit. As a ‘participant observer’ researcher, I have been acutely aware of my influence on the students and Studio learning environment, on my ability to attend to and record data as faithfully as possible, the data that I chose to collect, the observations I chose to, or sub-consciously chose not to make and the importance that I have ascribed to various results and conclusions. Readers who strongly believe that research can and should be totally objective will find this involvement unacceptable, and as such, a major limitation of the study. However, others argue (Erickson, 1986; Mann, 1987; Patton, 1990) that such involvement is a valid and legitimate methodology to adopt, provided inherent biases are recognised and documented.

6.4 Future research

This study found that different learning environments analysed using MDS resulted in visibly different spatial representations. With only two learning environments being represented here, it is not possible to say that the technique is diagnostic of a wide range of learning environments, however, this issue is worth further research. Traditionally, learning environment research has produced comparative numerical data in tables or graphs, but there is the possibility that the data will result in recognisable patterns that can be used for classification and diagnostic purposes.

Although this study contributes to research in epistemological beliefs, it also highlights the need for more research on and about the construct. It is likely that re-analysis of a larger sample of students' responses to items in the Questionnaire on Epistemological Beliefs will produce a structure different from that hypothesised by Schommer. Whether by factor analysis of all 63 items, or the use of multidimensional scaling or other techniques, other plausible structures are worth investigating. Considering the strong belief in this population about the role of the teacher in learning, why is the belief dimension Omniscient Authority not isolated by the Questionnaire on Epistemological Beliefs? To this end, the validity of individual items is also worth investigating.

This study supports the assertion of Hofer and Pintrich (1997) who suggest that beliefs about structure and source of knowledge be regarded as different from beliefs about acquisition of knowledge or learning. In this study, students' beliefs about the structure and certainty of knowledge have been found to influence the way that students' prefer to learn physics. Their beliefs about the source of knowledge and about learning are related to their perceptions of the learning environment, in particular teacher behaviours, but are apparently not related to the way they prefer to learn physics. This poses the questions:

- Are all epistemological beliefs subject-dependent or only some?
- Is belief in Omniscient Authority (or Expert Authority) only related to learning in specific disciplines, such as physics?

Finally, research into the effect and value of a constructivist assessment model should be undertaken. Included in this might be alternatives to traditional examinations, more types of formative assessment or even self- assessment activities incorporated into a portfolio.

6.5 References for Chapter 6

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APPENDICES

A.1 Instruments

This section contains all test and survey instruments as listed below:

1. Semester 1 Exam
2. Quantum Mechanics Test
3. Force & Motion Conceptual Evaluation (FMCE)
4. Thermal Concept Evaluation (TCE)
5. Questionnaire on Epistemological Beliefs (QEB)
6. IT Self-efficacy Beliefs Questionnaire
7. University Social Constructivist Learning Environment Survey (USCLES)
8. Self Monitoring and Reflection Form (SMARF)
9. Exit Survey
10. Study Preferences Survey

A.1.1 Semester 1 examination

CURTIN UNIVERSITY OF TECHNOLOGY
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF APPLIED PHYSICS

FIRST SEMESTER EXAMINATION - JUNE 1999

UNIT: **PARTICLES AND WAVES 101 /** INDEX NO: **01737**
AVIATION PHYSICS **10577**

INSTRUCTIONS:

TIME ALLOWED: TWO HOURS, preceded by a ten minute reading period, during which time only notes may be made. If you wish to make notes please use the question paper only, NOT the computer marked answer form. The supervisor will indicate when answering may commence.

ANSWER: All 44 multiple-choice questions. Each question is worth equal marks. Mark the **most** correct answer on the computer marked answer form, using a soft lead pencil.

Both the question paper and answer form are to be handed in SEPARATELY to the supervisor.
Make sure your name and student number are on the question paper and on the computer marked answer form.
To be supplied by the student: soft pencils, eraser and any calculator plus one, double sided, A4 sheet of notes.
To be supplied by the university: question paper & computer marked answer form.

FORMULA SHEET ATTACHED AT END

NAME:	**STUDENT No:**

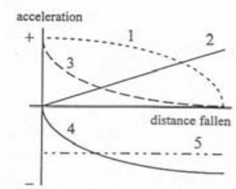
DATA:

Acceleration due to gravity	g	$= 9.8$ m s^{-2}
Speed of light	c	$= 3.0 \times 10^8$ m s^{-1}
Speed of sound in air (20°C)		$= 340$ m s^{-1}
Density of water		$= 1000$ kg m^{-3}
Mass of the Earth		$= 5.98 \times 10^{24}$ kg
Radius of the Earth		$= 6.37 \times 10^6$ m
Mass of the Earth's Moon		$= 7.36 \times 10^{22}$ kg
Radius of the Moon		$= 1.74 \times 10^6$ m
Distance from the Sun to the Earth		$= 1.50 \times 10^{11}$ m
Universal Gravitational Constant	G	$= 6.67 \times 10^{-11}$ N m^2 kg^{-2}

Moment of Inertia I for a particle (mass M) at a distance R from the axis of rotation = MR^2
Moment of Inertia I for a hollow cylinder = MR^2 (about the cylinder axis)
Moment of Inertia I for a solid cylinder = $(1/2)MR^2$ (about the cylinder axis)
Moment of Inertia I for a hollow sphere = $(2/3)MR^2$ (about any diameter)
Moment of Inertia I for a solid sphere = $(2/5)MR^2$ (about any diameter)

SECTION A - MECHANICS

1. A ball is thrown horizontally from a cliff. Ignoring air resistance, a graph of the acceleration of the ball versus the distance fallen could best be represented by (in the diagram)

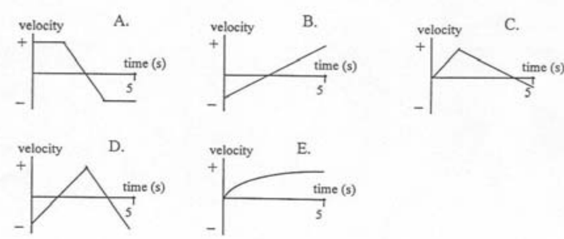


A. 1
B. 2
C. 3
D. 4
E. 5

2. A football is kicked with an initial velocity of $10\,\mathbf{i} + 15\,\mathbf{k}$ ms^{-1} (where **k** is positive upwards). At the top if its trajectory, the velocity and acceleration of the ball (with **v** in ms^{-1} and **a** in ms^{-2}) are

A.	$\mathbf{v} = 0$	$\mathbf{a} = 9.8\,\mathbf{k}$
B.	$\mathbf{v} = 10\,\mathbf{i}$	$\mathbf{a} = 9.8\,\mathbf{k}$
C.	$\mathbf{v} = 10\,\mathbf{k}$	$\mathbf{a} = -9.8\,\mathbf{i}$
D.	$\mathbf{v} = 10\,\mathbf{i}$	$\mathbf{a} = -9.8\,\mathbf{k}$
E.	$\mathbf{v} = 15\,\mathbf{k}$	$\mathbf{a} = -9.8\,\mathbf{k}$

3. For which one of the velocity – time graphs below would the particle be farthest from the origin at t = 5 s? All graphs have the same scales on the x- and y-axes.

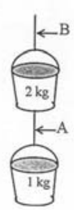


4. In an industrial sedimentation process, particles are allowed to settle out in a fluid, so as to physically separate materials of different density. As they drift to the bottom, the fluid drag force at any time t, is given by $F_{drag} \propto v$, where v is their speed at time, t. In separating finely crushed gold ore, if the "dirt" particles reach a terminal speed of 0.10 ms^{-1}, similar sized particles of gold ore, with a density about 5 times that of the "dirt", will have a terminal speed of (ms^{-1})

A. 0.05 B. 0.02 C. 0.1 (independent of density)
D. 0.2 E. 0.5

5. Two tug-of-war teams are pulling on the ends of a rope, each team with a force of 1000 N. If the rope is not accelerating, the tension in the rope (in N) is:
A. 0
B. 500
C. 1000
D. 2000
E. 4000

6. Two buckets, of mass 2.0 kg and 1.0 kg are pulled up with an acceleration of 0.50 ms^{-2}, as shown in the figure. The two cords have negligible mass. The tension in each cord (in newton) is



A. A = 10 and B = 31

B. A = B = 31

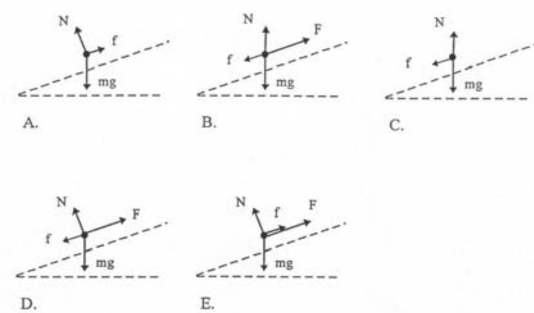
C. A = 10 and B = 20

D. A = B = 15.5

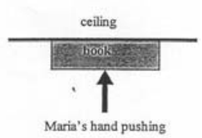
E. A = 9.8 and B = 29

7. A package is on a trolley and a worker is pulling it so that it accelerates up a ramp.

Which one of the free body diagrams below is correct for this situation?
The forces shown are: mg – gravitational force; N – normal force;
f – frictional force; F – force due to the worker;

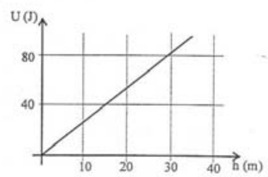


8. Maria raises a book up on her hand and pushes it up against the horizontal ceiling of her room as shown in the figure. The book weighs 20 N and she pushes upward with a force of 25 N. Select from the choices below the pair that correctly gives the magnitude of the contact forces, in newton, between the ceiling and the book (first) and between the book and her hand (second).



A. 45, 45 B. 5, 45 C. 5, 25 D. 25, 5 E. 5, 20

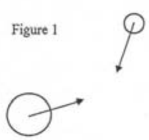
9. A plot of the gravitational potential energy, U, of a 1.0 kg brick as a function of its height, h, above the surface of a planet shows that the gravitational acceleration (in ms^{-2}) at the surface of the planet is

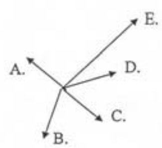


A. 1.5
B. 2.7
C. 3.3
D. 6.0
E. 9.8

10. The momentum vectors of two pucks, moving without friction across an air table, are shown in Figure 1, before the pucks collide. On colliding, the pucks stick. The vector that correctly represents the total momentum of the pucks after the collision is

Figure 1





11. Human beings suffer "blackout" if an acceleration of greater than about 10 g's is sustained for any length of time. A jet aircraft pulls out of a steep dive by moving in a vertical arc while maintaining a constant speed of 1800 km/h (500 m/s). The smallest radius of the arc, in km, that would result in an acceleration of less than 10 g's is

A. 0.85 B. 1.7 C. 2.6 D. 3.8 E. 6.3

12. Freeway entrance and exit ramps commonly form parts of circles. Consider an exit ramp banked so that a car moving at 40 km/h (11 m/s) would not have to rely on friction to round the curve without skidding.
To design a ramp with the same angle of banking for an exit speed of 80 km/h one should

A. decrease radius by factor of $\sqrt{2}$
B. decrease radius by factor of 4
C. increase radius by factor of $\sqrt{2}$
D. increase radius by factor of 4
E. increase radius by factor of 2

13. Consider the statements: The moment of inertia of a body depends on

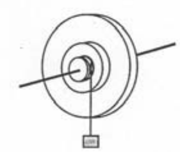
(i) the mass of the body.
(ii) the size of the body.
(iii) the shape of the body.
(iv) the location of the rotational axis.

Which one of the following is correct concerning these statements?

A. (i) and (ii) are correct.
B. (i), (ii) and (iii) are correct.
C. (i), (ii) and (iv) are correct.
D. (i), (iii) and (iv) are correct.
E. All of the statements are correct.

14. The wheel shown in the diagram is free to rotate about its axis. A string is wound around the smallest radius and a mass M hung from it as shown. The experiment is then repeated with the string wound around the larger radius. If α is the angular acceleration of the wheel and τ the torque exerted on the wheel in the second experiment, it would be found that

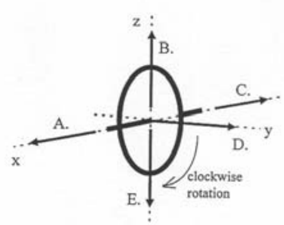
	α	τ
A.	no change	no change
B.	increases	increases
C.	decreases	increases
D.	increases	no change
E.	no change	increases



15. If the angular momentum of a system is constant, which of the following statements must be TRUE?

A. No torque acts on any part of the system.
B. Zero net torque acts on the system.
C. Zero net torque acts on each part of the system.
D. A constant external torque acts on the system.
E. A constant torque acts on each part of the system.

16. A wheel is rotating about a fixed axis, the x-axis, as shown in the diagram. A torque that would cause the wheel to slow down is best represented by which vector?



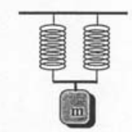
17. Five homogeneous planets have relative masses and sizes as shown in the figure below. A person would weigh <u>most</u> on which planet?

planet:	A.	B.	C.	D.	E.
radius:	R	R/2	2R	R/2	2R
Mass:	M	M/2	2M	M	M/2

18. The bulk modulus of aluminum is 7.0×10^{10} N m^{-2}. The pressure on a block of aluminum is increased by 8.0 atmospheres (8.1×10^{5} Pa). If the volume of the block is 0.14 m^3, its volume decreases by

A. 1.2×10^{-6} m^3
B. 1.4×10^{-11} m^3
C. 1.6×10^{-6} m^3
D. 1.1×10^{-5} m^3
E. 0, since metals are incompressible

19. Two identical springs each have a force constant k. A mass, m is hung from the two springs as shown in the diagram. The force constant for this system is



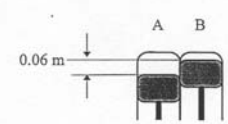
A. 2k B. 4k C. k/2 D. k/4

E. Can't be determined unless mass, m is known.

The following information refers to the next two (2) questions, 20 & 21.

The motions of the pistons in a car engine are approximately simple harmonic. Two such pistons are shown in the figure below. Piston B is at the top of its motion and about to move down and piston A is at the bottom of its motion and about to move up. The engine is running at 1200 rev/ min.

20. Relative to piston B, the phase of piston A is:



A. $+$ or $-\pi$
B. $+\pi/2$
C. $-\pi/2$
D. $+3\pi/4$
E. $-3\pi/4$

21. An equation giving the displacement of piston B as a function of time, with t = 0 defined by the condition shown in the figure is (in SI units):

A. 0.06 sin(1200 t) B. 0.03 sin(1200π t) C. 0.03 cos(40 t)
D. 0.06 cos(20π t) E. 0.03 cos(40π t)

22. When damping is added to an oscillating system, the frequency

A. increases slightly.
B. does not change.
C. decreases slightly.
D. can increase or decrease depending on the amount of damping.
E. depends on the amplitude of oscillation.

END OF MECHANICS QUESTIONS

SECTION B - WAVES

23. A surfer paddles out beyond the breaking surf to a deep-water region where the ocean waves are sinusoidal in shape, with crests 14 m apart. She rises a vertical distance of 3.6 m from wave trough to crest, in a time of 1.5 s.
What is the speed of the waves, in ms^{-1}?

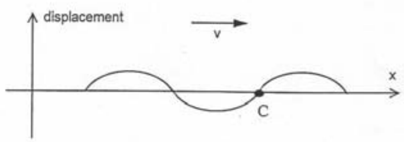
A. 2.3 B. 4.7 C. 8.3 D. 19 E. 37

24. The speed of S (transverse) and P (longitudinal) earthquake waves through the Earth's mantle are approximately 4 km/s and 8 km/s respectively. If the average density of the mantle is 5000 kgm^{-3}, the shear modulus (GNm^{-2}) of the Earth's mantle is approximately

A. 0.08 B. 0.3 C. 80 D. 180 E. 300

25. Part of a continuous, transverse sinusoidal wave is shown below moving in the positive x direction. The direction of the instantaneous velocity of a particle of the medium at point "C" is:

A. ↓ B. ↑ C. → D. ↗ E. no direction; speed is zero



26. Which one of the following statements is FALSE?

A. Total internal reflection can only occur for light travelling from a "slow" into a "fast" medium.
B. Two sinusoidal waves of the same frequency and amplitude, travelling in opposite directions, combine to form a standing wave of the same frequency.
C. The particle speed in a wave depends on the wave amplitude.
D. Travelling waves in one dimension can always be expressed as a function of either $x + vt$ or $x - vt$.
E. The Doppler frequency shift for sound waves is the same regardless of whether it is the source or the detector that are moving.

27. Two identical travelling waves, moving in the same direction are out of phase by $3\pi/2$ radian. The amplitude of the resultant wave in terms of the common amplitude A, of the two combining waves is

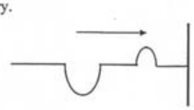
A. zero B. 0.85A C. A D. 1.4A E. 2A

28. A string of length 2.00 m is fixed at both ends and is vibrating according to $y(x, t) = 0.040 \sin 2\pi x \cos 2\pi t$, with quantities in SI units.

The total number of nodes, including at the ends, exhibited along the string is

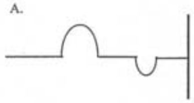
A. 3 B. 4 C. 5 D. 6 E. 25

29. The figure below shows two idealised pulses travelling to the right, along a string, towards a fixed boundary.

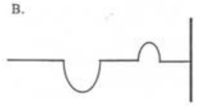


After both have been reflected the string shape could appear as

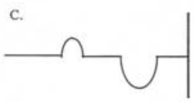
A.



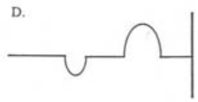
B.



C.



D.



30. A long sealed tube filled with air at atmospheric pressure and normal room temperature, resonates with a *fundamental* frequency of 440 Hz. The tube is then evacuated and filled with helium gas under the same conditions. If the velocity of sound in helium is 965 ms^{-1}, the *fundamental* frequency of vibration (Hz) would be

A. 155 B. 220 C. 880 D. 1250 E. 3500

31. A pair of similar loudspeakers, facing the same direction, are 1.00 m apart. A person stands 4.00 m from one speaker and is just a little further away from the other one. What is this extra distance if the person experiences destructive interference of the sound waves when the speakers sounds a "concert A" note of frequency 440 Hz?

A. 0.12 B. 0.20 C. 0.39 D. 0.78 E. 1.6

32. The largest number of beats per second will be heard from which pair of tuning forks?

A. 200 and 201 Hz B. 763 and 771 Hz C. 1534 and 1540 Hz
D. 256 and 260 Hz E. 8420 and 8422 Hz

33. An item of personal protection is a "screamer" - a compact high pitched noise generator powered by compressed air. The idea is that when activated this will deter a would-be attacker. A particular "screamer" generates 110 dB at a distance of 1 m. At what distance would the intensity drop to that of a noisy street scene, about 70 dB?

A. 40 m B. 100 m C. 300 m D. 1 km E. 10 km

34. A jet engine emits a whine at a frequency of 3 kHz. When the jet is moving directly away from an observer at half the speed of sound, the observer hears a frequency of (in Hz)

A. 1000 B. 1500 C. 2000 D. 2500 E. 4500

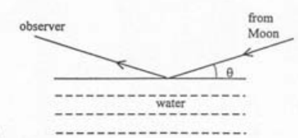
35. An ambulance is travelling at 34.0 m/s along a straight stretch of highway. A car is travelling at 17.0 m/s towards the moving ambulance along the same stretch of road? What is the ratio of the pitch heard by the passengers in the car to that emitted, f'/f_0 ?

A. (340 – 34)/ (340 + 17)
B. (340 + 34)/ (340 + 17)
C. (340 – 34)/ (340 – 17)
D. (340 + 51)/ 340
E. (340 + 34)/ (340 – 17)

36. Unpolarized light of intensity I_0 falls on two polarizers, one of which is rotated until no light is transmitted, so the polarizer axes are perpendicular. A third polarizer is then inserted between the other two, with its axis at 45° to each of theirs. What is the intensity of light transmitted by the system of three polarizers?

A. 0 B. $I_0/16$ C. $I_0/8$ D. $I_0/4$ E. $I_0/2$

37. At what angle above the horizontal would the moon be if its image, reflected in calm water, was completely plane polarised (n_{water} = 1.33)?



A. 37° B. 49°
C. 59° D. 27°
E. It is impossible for the moon's image to be completely plane polarised under these circumstances.

38. The adjacent figure shows the interference rings formed when monochromatic light illuminates the thin wedge of air formed between a very flat glass plate and a lens, known as *Newton's Rings*.

The central spot is dark because

A. the air film is much thinner than the wavelength.
B. one of the interfering rays undergoes a phase shift of π and the film is much thinner than the wavelength.
C. both of the interfering rays undergo a phase shift of π and the film is much thinner than the wavelength.
D. the wavelength in glass is less than the wavelength in air.
E. the film is, on average, about a quarter of a wavelength thick and one of the interfering rays undergoes a phase shift of π.

39. Which one of the following statements is FALSE?

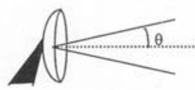
A. A path difference of one wavelength is equivalent to no phase difference at all.
B. In a beam of "coherent" light, such as laser light, all the photons are in phase.
C. A telescope used to observe a star produces an image consisting of a central disc and surrounding rings.
D. In a Young's type double slit experiment, light is first passed through a single slit so as to produce two coherent sources.
E. Sound can be heard around the edge of a building because of refraction.

40. Polarization experiments provide evidence that light is

A. a transverse wave.
B. a longitudinal wave.
C. a stream of particles.
D. nearly monochromatic.
E. an electromagnetic wave.

The following information refers to the next two (2) questions, 41 and 42.

A navy cruiser patrolling the north-west Australian waters, has a circular antenna of diameter of 2.25 m and uses radar with a wavelength of 16.0 mm. The antenna is used for both transmission and reception of its radar signals.



41. The total angular width, 2θ, of the emitted beam (= the central maximum) is:

A. 23 B. 12° C. 3.0° D. 1.0° E. 0.087°

42. Assuming the Rayleigh criterion applies, at a range of 20 km, what is the smallest distance between two fishing boats that will still allow them to be resolved as two objects?

A. 80 m B. 170 m C. 600 m D. 1.3 km E. 4.7 km

43. Monochromatic light from a red diode laser of wavelength 670 nm is normally incident on a diffraction grating. If the first order maximum is deviated by an angle of 36°, the grating constant, d, in nm, is:

A. 335 B. 390 C. 670 D. 790 E. 1140

44. Figure (i) below shows a double slit pattern obtained using monochromatic light. Consider the following five possible changes in conditions:

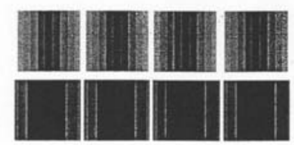
1. increase the number of slits
2. increase the wavelength
3. decrease the wavelength
4. increase the separation between the slits
5. decrease the separation between the slits

Which of the above would change Figure (i) into Figure (ii)?

A. 2 and 4 only B. 3 and 5 only C. 1, 3 and 5
D. 1 only E. 4 only

(i)

(ii)



END OF QUESTIONS

END OF PAPER

FORMULA SHEET FOLLOWS

A.1.2 Quantum Mechanics test

CURTIN UNIVERSITY OF TECHNOLOGY
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF APPLIED PHYSICS

SUBJECT: **Structure of Matter 102** (Studio class) **November 1999**
Semester test 2: Quantum Physics

TIME: 1 hour

INSTRUCTIONS: Answer all questions on the mark sheet.
Total marks for this test = 36
The first 15 questions are multiple choice. Each question is worth 2 marks.
The next 6 questions are true/false. Each question is worth 1 mark.

NAME:	**STUDENT NUMBER:**

DATA

Speed of light	c	$= 3.00 \times 10^{8}$ m/s
Planck's Constant	h	$= 6.63 \times 10^{-34}$ J s
Electronic charge	e	$= 1.6 \times 10^{-19}$ C
Atomic mass unit	u	$= 1.660 \times 10^{-27}$ kg
	$1u \times c^2 = 931$ MeV	
Rest mass of an electron	m_e	$= 9.11 \times 10^{-31}$ kg $= 0.511$ MeV/c^2
Rest mass of an proton	m_p	$= 1.67 \times 10^{-27}$ kg
		$= 1.007278$ u $= 938$ MeV/c^2
1 electron Volt	1eV	$= 1.60 \times 10^{-19}$ J

FORMULA SHEET

$$\frac{\partial^2\Psi}{\partial x^2} = \frac{-2m}{\hbar^2}(E-U)\Psi \qquad |\Psi|^2 dx = P(x)dx \qquad \int|\Psi|^2 dx = 1$$

$$\Delta x\Delta p \geq \hbar \qquad E_1 - E_2 = \frac{2\pi^2 me^4}{ch^3(4\pi\varepsilon_o)^2}\left(\frac{1}{n_2^2}-\frac{1}{n_1^2}\right) \qquad E = hf$$

$$\Psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right) \qquad \Psi_{1s}(r) = \frac{1}{\sqrt{\pi a_o^3}}e^{-r/a_o}$$

$$E_n = \left(\frac{h^2}{8mL^2}\right)n^2 \qquad E_n = \frac{-2\pi^2 me^4}{n^2h^2(4\pi\varepsilon_o)^2}$$

$$E_{rot} = \frac{\hbar^2}{2I}[J(J+1)] \qquad E_{vib} = (v+\tfrac{1}{2})hf$$

1. The speed of an electron is measured at 2×10^4 m/s to an accuracy of 0.005%. The uncertainty in determining the position of this electron is
   (a) 24 mm
   (b) 120 μm
   (c) 5.0 nm
   (d) 90 pm
   (e) 0.50 fm

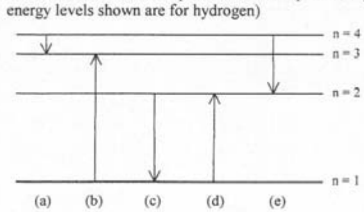
2. A solid state pulsed laser has an energy of 400 mJ/pulse. If the wavelength of the light is 1.06 μm, how many photons are there in each pulse?
   (a) 2×10^{25}
   (b) 2×10^{21}
   (c) 3×10^{18}
   (d) 6×10^{38}
   (e) 2×10^{18}

3. In an experimental arrangement to measure photoelectric effect, 0.63 V is needed to reduce the photoelectric current to zero. The material, which is being illuminated with blue light of wavelength 400nm, therefore has a work function (in eV) equal to
   (a) 2.48
   (b) 3.11
   (c) 0.63
   (d) 3.97×10^{-19}
   (e) 1.01×10^{-19}

4. The ground state wave function for hydrogen is proportional to e^{-r/a_o}. The radial probability density, P(r), is therefore proportional to:
   (a) e^{-r/a_o} (b) e^{-2r/a_o} (c) r^2e^{-r/a_o} (d) re^{-r/a_o} (e) r^2e^{-2r/a_o}

5. The quantisation of energy, E = *nhf*, is not important for an ordinary pendulum (mass suspended on a string) because the
   (a) formula applies only to atoms.
   (b) formula applies only to mass-spring oscillators.
   (c) value of *h* for a pendulum is too large.
   (d) allowed energy levels are too closely spaced.
   (e) allowed energy levels are too widely spaced.

6. Which transition below represents the absorption of a photon of the shortest wavelength? (The energy levels shown are for hydrogen)



7. Electron states of an atom which constitute a single "subshell" have what in common?
   (a) same n value
   (b) same l value
   (c) same n value and same l value
   (d) same l value and same m_l value
   (e) same set of all four quantum numbers

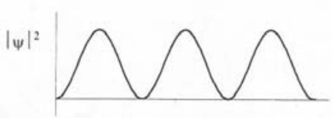
8. Consider the three energies, K, U, E (kinetic, potential, total) pertaining to a hydrogen atom in some state specified by a quantum number n. Assuming the convention of zero potential energy for infinite separation, the respective values of K, U and E must be
   (a) +, +, + (b) +, +, – (c) +, –, + (d) +, –, – (e) –, –, –

9. The units of $\hbar$ are those of
   (a) energy (b) power (c) frequency (d) momentum (e) angular momentum

10. If a wave function ψ for a particle moving along the x-axis is "normalised" then:
   (a) $\int |\Psi|^2 dt = 1$ (b) $\int |\Psi|^2 dx = 1$ (c) $\frac{\partial \Psi}{\partial x} = 1$

   (d) $\frac{\partial \Psi}{\partial t} = 1$ (e) $|\Psi|^2 = 1$

11. An electron is in an infinitely high square well potential.



Based on the graph above, the value of the quantum number, n, is
   (a) 1 (b) 2 (c) 3 (d) 4 (e) 5

12. The number of values of the orbital quantum number l associated with the principle quantum number $n = 3$ is:
   (a) 1 (b) 2 (c) 3 (d) 4 (e) 5

13. If P(r) is the radial probability density, then the probability that the separation of the electron and proton is between r and dr is:
   (a) $4\pi r^2 |P(r)| dr$ (b) $P(r)dr$ (c) $|P(r)|^2 dr$

   (d) $\pi r^2 P(r) dr$ (e) $4\pi P(r) dr$

14. A free electron has a momentum of 5.0×10^{-24} kg.m/s. The wavelength (in m) of matter waves associated with this electron are:
   (a) 1.33×10^{-8}
   (b) 1.33×10^{-10}
   (c) 1.33×10^{-12}
   (d) 1.33×10^{-14}
   (e) none of these

15. The fundamental vibrational frequency of HF is 8.72×10^{13} Hz. The energy associated with a transition from the 10^{th} to the 9^{th} vibrational quantum number (in eV) is
   (a) 3.6
   (b) 0.36
   (c) 0.06
   (d) 0.6
   (e) 0.18

The remaining questions require true (a) or false (b) answers. Each question is worth 1 mark.

For a particle trapped in a box in one dimension:

U(x) = 0 for $^{-a}/_2 < x < ^{+a}/_2$ and U(x) = ∞ elsewhere

For such a particle, the solution for the time-independent Schrödinger equation:

$\frac{\partial^2 \Psi}{\partial x^2} = \frac{-2m}{\hbar^2}(E - U)\Psi$ is: $\psi(x) = A_n \cos k_n x$ for n = 1,2,3 ……

and $\psi(x) = B_n \sin k_n x$ for n = 1,2,3 ……

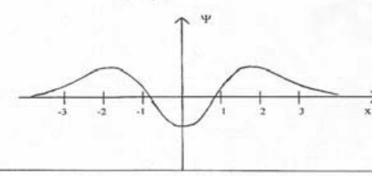
16. The expression for k_n *is* $k_n = \frac{n\pi}{2a}$

17. The energy level corresponding to a particular n value is

$$E_n = \frac{n^2 h^2}{8ma^2} \quad \text{for } n = 1,2,3 \ldots$$

18. The normalisation constants for the wavefunctions are $A_n = B_n = \sqrt{\frac{2}{a}}$

Now consider the case of a particle in a one-dimensional square well potential of finite magnitude U_o outside the well and U = 0 inside the well. The particle occupies a state which has the wave function $\psi(x)$ displayed below:



19. The particle energy $E > U_o$

20. The width of the well is 3 units (i.e. the well extends from –1.5 to +1.5)

21. The quantum number for the state displayed is 1.

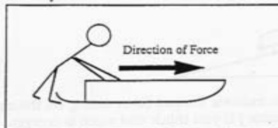
A.1.3 Force and Motion Conceptual Evaluation

Particles and Waves 101: **Force and Motion Conceptual Evaluation**

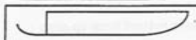
Directions: Answer all questions in the spaces on the answer sheet.
Answer questions 3a, 7a and 46a on the answer sheet.

A sled on ice moves in the ways described in questions 1-7 below. *Friction is so small that it can be ignored.* A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would **keep the sled moving** as described in each statement below.

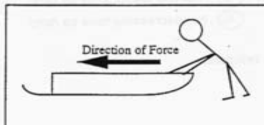
You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice J.



A. The force is toward the **right** and is **increasing** in strength (magnitude).
B. The force is toward the **right** and is of **constant** strength (magnitude).
C. The force is toward the **right** and is **decreasing** in strength (magnitude).



D. No applied force is needed



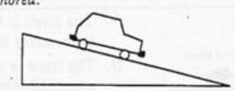
E. The force is toward the **left** and is **decreasing** in strength (magnitude).
F. The force is toward the **left** and is of **constant** strength (magnitude).
G. The force is toward the **left** and is **increasing** in strength (magnitude).

____1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?
____2. Which force would keep the sled moving toward the right at a steady (constant) velocity?
____3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
____4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
____5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?
____6. The sled is slowing down at a steady rate and has an acceleration to the right. Which force would account for this motion?
____7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

3a. Describe in words the force required and your reasoning in reaching your answer to question 3. (**Answer on the answer sheet** and use as much space as you need)

7a. Describe in words the force required and your reasoning in reaching your answer to question 7. (**Answer on the answer sheet** and use as much space as you need)

Questions 8-10 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. *Friction is so small it can be ignored.*



Use one of the following choices (A through G) to indicate the **net force** acting on the car for each of the cases described below. Answer choice J if you think that none is correct.

(A) Net **constant** force **down** ramp
(B) Net **increasing** force **down** ramp
(C) Net **decreasing** force **down** ramp
(D) Net force zero
(E) Net **constant** force **up** ramp
(F) Net **increasing** force **up** ramp
(G) Net **decreasing** force **up** ramp

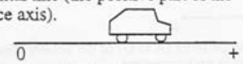
____8. The car is moving up the ramp after it is released.
____9. The car is at its highest point.
____10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through G) to indicate the force acting on the coin for each of the cases described below. Answer choice J if you think that none is correct. **Ignore any effects of air resistance.**

A. The force is **down** and constant.
B. The force is **down** and increasing
C. The force is **down** and decreasing
D. The force is zero.
E. The force is **up** and constant.
F. The force is **up** and increasing
G. The force is **up** and decreasing

____11. The coin is moving upward after it is released.
____12. The coin is at its highest point.
____13. The coin is moving downward.

Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (A through H) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice J.

__14. The car moves toward the right (away from the origin) with a steady (constant) velocity.

__15. The car is at rest.

__16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).

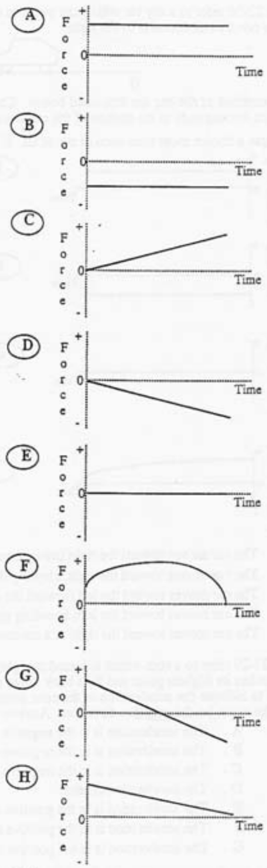
__17. The car moves toward the left (toward the origin) with a steady (constant) velocity.

__18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).

__19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).

__20. The car moves toward the right, speeds up and then slows down.

__21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.

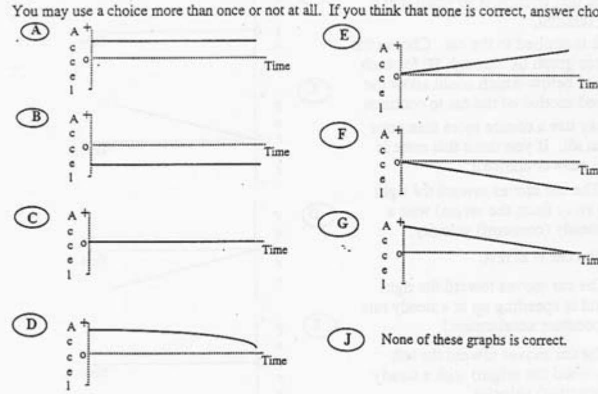


J None of these graphs is correct.

Questions 22-26 refer to a toy car which can move to the right or left along a horizontal line (the + distance axis). The positive direction is to the right.

Different motions of the car are described below. Choose the letter (A to G) of the **acceleration-time** graph which corresponds to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice J.



J None of these graphs is correct.

____22. The car moves toward the right (away from the origin), speeding up at a steady rate.

____23. The car moves toward the right, slowing down at a steady rate.

____24. The car moves toward the left (toward the origin) at a constant velocity.

____25. The car moves toward the left, speeding up at a steady rate.

____26. The car moves toward the right at a constant velocity.

Questions 27-29 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through G) to indicate the acceleration of the coin during each of the stages of the coin's motion described below. Take up to be the positive direction. Answer choice J if you think that none is correct.

A. The acceleration is in the negative direction and constant.
B. The acceleration is in the negative direction and increasing
C. The acceleration is in the negative direction and decreasing
D. The acceleration is zero.
E. The acceleration is in the positive direction and constant.
F. The acceleration is in the positive direction and increasing
G. The acceleration is in the positive direction and decreasing

____27. The coin is moving upward after it is released.

____28. The coin is at its highest point.

____29. The coin is moving downward.

Questions 30-34 refer to collisions between a car and trucks. For each description of a collision (30-34) below, choose the one answer from the possibilities A though J that best describes the size (magnitude) of the forces between the car and the truck.

A. The truck exerts a larger force on the car than the car exerts on the truck.
B. The car exerts a larger force on the truck than the truck exerts on the car.
C. Neither exerts a force on the other; the car gets smashed simply because it is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't exert a force on the truck.
E. The truck exerts the same amount of force on the car as the car exerts on the truck.
F. Not enough information is given to pick one of the answers above.
J. None of the answers above describes the situation correctly.

In questions 30 through 32 the truck is much heavier than the car.

_____30. They are both moving at the same speed when they collide. Which choice describes the forces?
_____31. The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?
_____32. The heavier truck is standing still when the car hits it. Which choice describes the forces?

In questions 33 and 34 the truck is a small pickup and is the same weight as the car.

_____33. Both the truck and the car are moving at the same speed when they collide. Which choice describes the forces?
_____34. The truck is standing still when the car hits it. Which choice describes the forces?

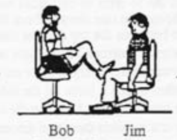
Questions 35-38 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

Pick one of the choices A through J below which correctly describes the size (magnitude) of the forces between the car and the truck for each of the descriptions (35-38).

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.
B. The force of the car pushing against the truck is less than that of the truck pushing back against the car.
C. The force of the car pushing against the truck is greater than that of the truck pushing back against the car.
D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.
E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.
J. None of these descriptions is correct.

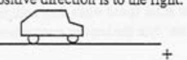
_____35. The car is pushing on the truck, but not hard enough to make the truck move.
_____36. The car, still pushing the truck, is **speeding up** to get to cruising speed.
_____37. The car, still pushing the truck, is at cruising speed and continues to travel at the **same speed**.
_____38. The car, still pushing the truck, is at cruising speed when the truck puts on its brakes and causes the car to **slow down**.

____39. Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,

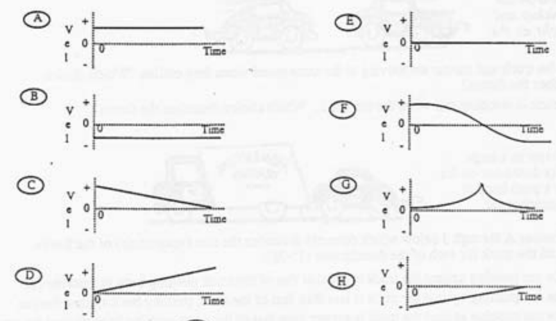


A. Neither student exerts a force on the other.
B. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.
C. Each student exerts a force on the other, but Jim exerts the larger force.
D. Each student exerts a force on the other, but Bob exerts the larger force.
E. Each student exerts the same amount of force on the other.
J. None of these answers is correct.

Questions 40-43 refer to a toy car which can move to the right or left along a horizontal line (the positive portion of the distance axis). The positive direction is to the right.



Choose the correct velocity-time graph (A - G) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer choice J.



J None of these graphs is correct.

___40. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?
___41. Which velocity graph shows the car reversing direction?
___42. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?
___43. Which velocity graph shows the car increasing its *speed* at a steady (constant) rate?

A sled is pulled up to the top of a hill. The sketch above indicates the shape of the hill. At the top of the hill the sled is released from rest and allowed to coast down the hill. At the bottom of the hill the sled has a speed v and a kinetic energy E (the energy due to the sled's motion). Answer the following questions. ***In every case friction and air resistance are so small they can be ignored.***

_44. The sled is pulled up a **steeper** hill of the **same** height as the hill described above. How will the velocity of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill? Choose the best answer below.

A. The speed at the bottom is greater for the steeper hill.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill because the sled travels further.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

_45. Compare the kinetic energy (energy of motion) of the sled at the bottom for the original hill and the steeper hill in the previous problem. Choose the best answer below.

A. The kinetic energy of the sled at the bottom is greater for the steeper hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

_46. The sled is pulled up a **higher** hill that is **less** steep than the original hill described before question 44. How does the speed of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill?

A. The speed at the bottom is greater for the higher but less steep hill than for the original.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

46a. Describe in words your reasoning in reaching your answer to question 46. (**Answer on the answer sheet** and use as much space as you need)

47. For the higher hill that is less steep, how does the kinetic energy of the sled at the bottom of the hill after it has slid down compare to that of the original hill?

A. The kinetic energy of the sled at the bottom is greater for the higher but less steep hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

ANSWER SHEET

Directions: <u>Answer all questions in the spaces on the answer sheet.</u>
<u>Answer questions 3a, 7a and 46a on the answer sheet.</u>

Name: ____________________ Student Number ________________________

1. _____	11._____	22._____
2. _____	12._____	23._____
3. _____	13._____	24._____
4. _____	14._____	25._____
5. _____	15._____	26._____
6. _____	16._____	27._____
7. _____	17._____	28._____
8. _____	18._____	29._____
9. _____	19._____	
10._____	20._____	
	21._____	

3a.____

____

____

7a.____

____

____

30._____	35._____	44._____
31._____	36._____	45._____
32._____	37._____	46._____
33._____	38._____	47._____
34._____	39._____	
	40._____	
	41._____	
	42._____	
	43._____	

46a. ____

____

____

A.1.4 Thermal Concept Evaluation

(Formerly known as the **Test of Thermal Physics Conceptual Understanding**)

This questionnaire is about <u>your</u> understandings about <u>temperature, heating and cooling</u>.
To help you visualise each situation, think of a group of friends in a well-equipped canteen or common room. Imagine that they are an observant and inquisitive lot who are interested in understanding common phenomena. They also explain their ideas to one another.
For each question, choose the answer that is closest to your understanding.
Record all answers on the coloured answer sheet.

PLEASE DO NOT WRITE ON THIS QUESTION PAPER
<u>Use the list of temperatures below to answer **questions 1-10**</u>.

A.	–10°C	B.	0°C	C.	5°C	D.	10°C	E.	20°C
F.	30°C	G.	37°C	H.	40°C	I.	50°C	J.	60°C
K.	70°C	L.	80°C	M.	90°C	N.	100°C	O.	110°C

Select **from the list above**, the temperature that you think applies in each situation below. **Write the letter on the answer sheet**.

1. The temperature of a person's blood.
2. The temperature of iceblocks stored in a refrigerator's freezer compartment.
3. The temperature of a half-melted ice-block lying on a bench-top.
4. The temperature of a person's skin (for example, their hand).
5. The temperature of water in an urn when it has just started to boil.
6. The temperature of water in the urn after it has been boiling continuously for 5 minutes.
7. The temperature of the steam above the boiling water in the urn.
8. The temperature of a boiling sugar/water solution in a saucepan on a stove-top.
9. Ken takes four iceblocks from the freezer and puts them into a glass of water. He stirs for a while until no more of the iceblocks appear to melt. What is the most likely temperature of the water at this stage?
10. Lee takes two cups of hot water (80°C) and mixes them with one cup of cool water (20°C). What is the most likely temperature of the mixture?

Nat takes a can of coke and a bottle of coke from the fridge, where they have been overnight and quickly measures the temperature of the coke in the <u>can</u> with a thermometer. The coke has a temperature of 7°C.

11A. What is the most likely temperature of the <u>coke in the bottle</u>?

a) less than 7°C

b) equal to 7°C
c) greater than 7°C
d) depends on the size of the bottle.

11B. What is the most likely temperature of the <u>coke can</u>?
a) less than 7°C
b) equal to 7°C
c) greater than 7°C
d) depends on the size of the can.

11C. What is the most likely temperature of the <u>bottle</u>?
a) less than 7°C
b) equal to 7°C
c) greater than 7°C
d) depends on the size of the bottle.

12. A few minutes later, Ned moves the coke can and then tells the others that the bench top underneath it feels colder than the rest of the bench.
a) Jon says: "The cold has been transferred from the coke to the bench."
b) Rob says: "The can has stopped the air in the room from warming the bench."
c) Sue says: "Heat has been transferred from the bench to the coke."
d) Fee says: "The can prevents the heat from the bench escaping to the air."

Whose explanation do you agree with?

13. Mal asks one group of students: "If I put 100g of ice at 0°C and 100g of water at 0°C into a freezer (which is at –10°C), which one will lose the greatest amount of heat?
a) Cat says: "The 100g of ice."
b) Ben says: "The 100g of water."
c) Nic says: "Neither, because they don't contain any heat."
d) Mat says: "Neither because they both contain the same amount of heat."
e) Jed says: "Neither, because you can't get water at 0°C."

Which one do you most agree with?

14. One of the group, Ben, then asks: "If I place the following four quantities into the freezer (which is at –10°C), which would lose the greatest amount of heat to the freezer?
a) 100 grams of ice at 0 °C
b) 100 grams of water at 5°C
c) 10 grams of water at 10°C
d) 1 gram of water at 20°C

Which do you think?

15. Mel is boiling water in a saucepan on the stove-top. What do you think is in the bubbles that form in the water?
a) Air
b) Oxygen
c) Hydrogen
d) Both oxygen and hydrogen.
e) Water vapour
f) There's nothing in the bubbles

16. Mel is actually cooking some eggs in the boiling water. She cools the eggs by dropping them into a bowl of cold water. How do they cool?
a) Temperature flows from the eggs to the water
b) Heat leaks out of the eggs and dissolves in the water
c) Cold passes out of the water and into the eggs

d) Energy escapes from the water to the eggs
e) Energy transfers from the eggs to the water

17. Dan simultaneously picks up two cartons of choc-milk, a cold one from the fridge and a warmer one that has been sitting on the bench-top for some time. Why do you think the carton from the fridge **feels colder** than the one from the bench-top?

Compared with the warmer carton, the cold carton---

a) contains more cold.
b) contains less heat.
c) is a better heat conductor.
d) is a poorer cold conductor.
e) conducts heat more rapidly from Dan's hand.
f) conducts cold more rapidly to Dan's hand.

18. Amy took two glass bottles containing water at 20°C and wrapped them in towelling face-washers. One of the face-washers was wet and the other was dry. 10 minutes later, she measured the water temperature in each. The water in the bottle with the wet face-washer was 18°C, the water in the bottle with the dry face-washer was 22°C. What do you think the room temperature was during this 'experiment'?

a) 15°C
b) 18°C
c) 20°C
d) 21°C
e) 26°C

19. Jan announces that she does not like sitting on the metal chairs in the room because "they are colder than the plastic ones".

a) Jim says: "They are not colder, they are at the same temperature."
b) Kip says: "They are colder because metal is naturally colder than plastic."
c) Lou says: "They are not colder, the metal ones just feel colder because they have more mass."
d) Mai says: "They are colder because metal radiates heat better than plastic."

With whom do you most agree?

20. Cal has a small jar of ball bearings with him. He shakes the jar continuously for about ten minutes. What can you say about the temperature of the ball bearings in the jar?

a) The temperature will be greater than when Cal started.
b) The temperature will be less than when Cal started.
c) The temperature will be the same as when Cal started.

21. Having selected an answer to the question above, which of the following do you think provides the best explanation?

a) Because no heat has been added or removed.
b) Because energy has been transferred to the ball bearings.
c) Because heat has flowed from his arm to the ball bearings.
d) Evaporation has occurred.

22. Ron reckons his Mum cooks kangaroo tail soup in a pressure cooker because it cooks faster than in a normal saucepan but doesn't know why. [Pressure cookers have a sealed lid so that the pressure inside rises well above atmospheric pressure.] Why does the food cook faster?

a) Col says: "It's because the pressure generates extra heat."
b) Emi says: "It's because the pressure causes water to boil at 110°C."

c) Fay says: "It's not the pressure that's important, it's because the steam is at a higher temperature than the boiling soup."
d) Tom says: "It's because pressure cookers spread the heat more evenly through the food."

Which person do you most agree with?

23. Pat reckons her Dad cooks cakes on the top shelf inside the electric oven because it is hotter at the top than at the bottom.

a) Pam agrees and says that it's hotter at the top because heat always rises.
b) Ray agrees but says it is hotter at the top because cooler air pushes hotter air up.
c) Sam agrees and says that it is hotter because the muffin tray concentrates the heat.
d) Tim disagrees with them all and says that the oven is the same temperature throughout.

Which person do you think is right?

24. Why do we wear jumpers in cold weather?

a) To keep the cold out.
b) To prevent heat loss.
c) To generate heat.
d) All of the above.

25. Vic takes a couple of frosty-fruits (icy-poles) from the freezer, where he had placed them the day before, and tells everyone that the wooden sticks are at a higher temperature than the ice part.

a) Ann says: "You're wrong, they are at the same temperature. Your skin is not a good thermometer."
b) Ros says: "You're wrong, they only feel different because the sticks contain more heat."
c) Deb says: "You're right because wooden sticks don't get as cold as ice does."
d) Ian says: "You're right because ice contains more cold than wood does."

26. Which person do you most agree with?

What is the lowest possible temperature that can be reached?

a) Below minus 500°C
b) Between minus 300°C and minus 500°C
c) Between minus 100°C and minus 300°C
d) Between 0°C and minus 100°C

27. Gay believes that different materials in an oven do not reach the same temperature. She demonstrates this to her group by putting 100 g of copper pieces and 100 g of aluminium pieces on heat-proof containers in an oven at 250°C. After about 20 minutes, she quickly drops the metals in separate, identical cups of water. The water with the aluminium in it reaches a higher temperature than the water with the copper in it. She concludes that the aluminium was at a higher temperature than the copper.

a) Joe says: "That's proof enough for me."
b) Kay says: "Your method is OK but I know you're not right."
c) Len says: "The aluminium heated the water more because it can hold more energy than the copper."
d) Ric says: "The metals were at the same temperature, but the aluminium was still hotter than the copper."

Whose opinion is closest to yours?

28. Kim takes a metal ruler and a wooden ruler from a pencil case. He announces that the metal one feels colder than the wooden one.
What is your preferred explanation?

a) Metal conducts energy away from his hand more rapidly than wood.
b) Wood is a naturally warmer substance than metal.
c) The wooden ruler contains more heat than the metal ruler.
d) Metals are better heat radiators than wood.
e) Heat does not flow from Kim's hand to the metal, but does flow from the wooden ruler to his hand.

29. Four students were discussing the dumb things they did as kids. The following conversation was heard:

a) Ali said: "I used to wrap my dolls in blankets but could never understand why they didn't warm up. I guess I still don't."
b) Nic replied: "It's because the blankets you used were probably poor insulators."
c) Lyn replied: "It's because the blankets you used were probably poor conductors."
d) Jay replied: "It's because the dolls were made of material which did not hold heat well."
e) Kev replied: "It's because the dolls were made of material which took a long time to warm up."
f) Joy replied: "You're all wrong."

Who do you agree with?

30. Bev is reading a multiple-choice question from a text book:
"Sweating cools you down because the sweat lying on your skin:

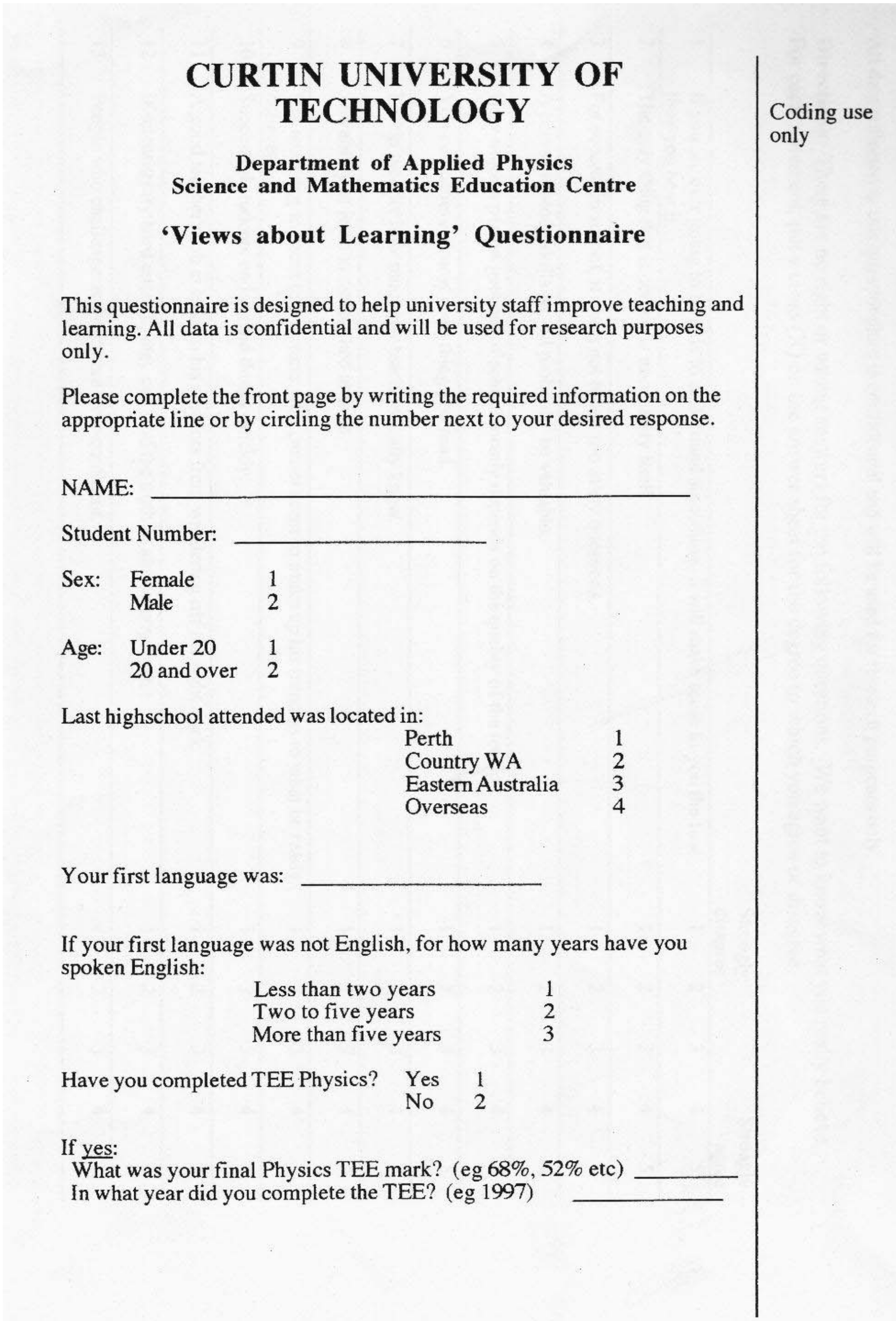
a) drains heat from the pores and spreads it out over the surface of the skin.
b) is the same temperature as your skin but is evaporating and so is carrying heat away.
c) wets the surface, and wet surfaces draw heat out more effectively than dry surfaces.
d) is slightly cooler than your skin because of evaporation and so heat is transferred from your skin to the sweat.

Which answer would you tell her to select?

THE END

A.1.5 Questionnaire on Epistemological Beliefs

For the purpose of this study the Questionnaire on Epistemological Beliefs was called the Views About Learning Questionnaire.



CURTIN UNIVERSITY OF TECHNOLOGY

Department of Applied Physics
Science and Mathematics Education Centre

'Views about Learning' Questionnaire

Coding use only

This questionnaire is designed to help university staff improve teaching and learning. All data is confidential and will be used for research purposes only.

Please complete the front page by writing the required information on the appropriate line or by circling the number next to your desired response.

NAME: ______________________________

Student Number: ______________

Sex: Female 1
Male 2

Age: Under 20 1
20 and over 2

Last highschool attended was located in:
Perth 1
Country WA 2
Eastern Australia 3
Overseas 4

Your first language was: ______________

If your first language was not English, for how many years have you spoken English:
Less than two years 1
Two to five years 2
More than five years 3

Have you completed TEE Physics? Yes 1
No 2

If yes:
What was your final Physics TEE mark? (eg 68%, 52% etc) ________
In what year did you complete the TEE? (eg 1997) ________

Views about Learning' Questionnaire

All data collected in this questionnaire is confidential and will be used for research purposes only.
Directions: There are no right or wrong answers for the following questions. We want to know what you really believe. For each statement, put a cross (X) on the answer sheet for the degree to which you agree or disagree.

		Strongly disagree			Strongly agree	
1	If you are ever going to be able to understand something, it will make sense to you the first time you hear it.	1	2	3	4	5
2	The only thing that is certain is uncertainty itself.	1	2	3	4	5
3	For success in school, it's best not to ask too many questions.	1	2	3	4	5
4	A course in study skills would probably be valuable.	1	2	3	4	5
5	How much a person gets out of school mostly depends on the quality of the teacher.	1	2	3	4	5
6	You *can* believe almost everything you read.	1	2	3	4	5
7	I often wonder how much my teachers really know.	1	2	3	4	5
8	The ability to learn is established at birth.	1	2	3	4	5
9	It is annoying to listen to a lecturer who cannot seem to make up his mind as to what he really believes.	1	2	3	4	5
10	Successful students understand things quickly.	1	2	3	4	5
11	A good teacher's job is to keep his students from wandering off the right track.	1	2	3	4	5

		Strongly disagree				Strongly agree
12	If scientists try hard enough, they can find the truth to almost anything.	1	2	3	4	5
13	People who challenge authority are over-confident.	1	2	3	4	5
14	I try my best to combine information across chapters or even across classes.	1	2	3	4	5
15	The most successful people have discovered how to improve their ability to learn.	1	2	3	4	5
16	Things are simpler than most professors would have you believe.	1	2	3	4	5
17	The most important aspect of scientific work is precise measurement and careful work.	1	2	3	4	5
18	To me studying means getting the big ideas from the text, rather than details.	1	2	3	4	5
19	Educators should know by now which is the best method, lectures or small group discussions.	1	2	3	4	5
20	Going over and over a difficult textbook chapter usually won't help you understand it.	1	2	3	4	5
21	Scientists can ultimately get to the truth.	1	2	3	4	5
22	You never know what a book means unless you know the intent of the author.	1	2	3	4	5
23	The most important part of scientific work is original thinking.	1	2	3	4	5
24	If I find the time to re-read a textbook chapter, I get a lot more out of it the second time.	1	2	3	4	5

		Strongly disagree			Strongly agree	
25	Students have a lot of control over how much they can get out of a textbook.	1	2	3	4	5
26	Genius is 10% ability and 90% hard work.	1	2	3	4	5
27	I find it refreshing to think about issues that authorities can't agree on.	1	2	3	4	5
28	Everyone needs to learn how to learn.	1	2	3	4	5
29	When you first encounter a difficult concept in a textbook, it's best to work it out on your own.	1	2	3	4	5
30	A sentence has little meaning unless you know the situation in which it is spoken.	1	2	3	4	5
31	Being a good student generally involves memorising facts.	1	2	3	4	5
32	Wisdom is not knowing the answers, but knowing how to find the answers.	1	2	3	4	5
33	Most words have one clear meaning.	1	2	3	4	5
34	Truth is unchanging.	1	2	3	4	5
35	If a person forgot details, and yet was able to come up with new ideas from a text, I would think they were bright.	1	2	3	4	5
36	Whenever I encounter a difficult problem in life, I consult with my parents.	1	2	3	4	5
37	Learning definitions word-for-word is often necessary to do well on tests.	1	2	3	4	5
38	When I study, I look for the specific facts.	1	2	3	4	5

		Strongly disagree			Strongly agree	
39	If a person can't understand something within a short amount of time, they should keep on trying.	1	2	3	4	5
40	Sometimes you just have to accept answers from a teacher even though you don't understand them.	1	2	3	4	5
41	If professors would stick more to the facts and do less theorising, one could get more out of university lectures.	1	2	3	4	5
42	I don't like movies that don't have an ending.	1	2	3	4	5
43	Getting ahead takes a lot of work.	1	2	3	4	5
44	It's a waste of time to work on problems which have no possibility of coming out with a clear-cut and unambiguous answer	1	2	3	4	5
45	You should evaluate the accuracy of information in a textbook, if you are familiar with the topic.	1	2	3	4	5
46	Often, even advice from experts should be questioned.	1	2	3	4	5
47	Some people are born good learners; others are just stuck with limited ability.	1	2	3	4	5
48	Nothing is certain, but death and taxes.	1	2	3	4	5
49	The really smart students don't have to work hard to do well in school.	1	2	3	4	5
50	Working hard on a difficult problem for an extended period of time only pays off for really smart students.	1	2	3	4	5
51	If a person tries too hard to understand a problem, they will most likely just end up being confused.	1	2	3	4	5

		Strongly disagree			Strongly agree	
52	Almost all the information you can learn from a textbook you will get during the first reading .	1	2	3	4	5
53	Usually you can figure out difficult concepts if you eliminate all outside distractions and really concentrate.	1	2	3	4	5
54	A really good way to understand a textbook is to re-organise the information according to your own personal scheme	1	2	3	4	5
55	Students who are "average" in school will remain "average" for the rest of their lives.	1	2	3	4	5
56	A tidy mind is an empty mind.	1	2	3	4	5
57	An expert is someone who has a special gift in some area.	1	2	3	4	5
58	I really appreciate instructors who organise their lectures meticulously and then stick to their plan.	1	2	3	4	5
59	The best thing about science courses is that most problems have only one right answer.	1	2	3	4	5
60	Learning is a slow process of building up knowledge.	1	2	3	4	5
61	Today's facts may be tomorrow's fiction.	1	2	3	4	5
62	Self-help books are not much help.	1	2	3	4	5
63	You will just get confused if you try to integrate new ideas in a textbook with knowledge you already have about a topic.	1	2	3	4	5

Administered by S. Yeo
Dept of Applied Physics
Curtin University of Technology

A.1.6 IT (self-efficacy beliefs) Survey

Survey: **Use of Information Technology**
All data collected in this questionnaire is confidential and will be used for research purposes only.

Directions: There are no right or wrong answers for the following questions. We want to know what you really believe.
For each statement, put a cross (X) on the answer sheet for the degree to which you agree or disagree.

Name: ______________________Student Number: ___________________

		Strongly disagree			Strongly agree	
1	I use email and the internet frequently.	1	2	3	4	5
2	I am less skilled at using a computer than most of my peers.	1	2	3	4	5
3	I find it easy to learn to use new programs.	1	2	3	4	5
4	I prefer to write out my work rather than type it on a computer.	1	2	3	4	5
5	I need to be shown new computer applications several times before I feel confident using them.	1	2	3	4	5
6	For me, the positives of using computers do not outweigh the negatives.	1	2	3	4	5
7	I teach many of my friends things that they need to know about using computers.	1	2	3	4	5
8	My computer skills have improved considerably over the last year.	1	2	3	4	5

A.1.7 University Social Constructivist learning Environment Survey (Combined actual and preferred format)

What <u>actually</u> happens in Structure of Matter 102 classes and what I would <u>prefer</u> to happen in Structure of Matter 102 classes

DIRECTIONS

1. Purpose of the Questionnaire

This questionnaire describes teaching and learning practices which could take place in university classes.

The questionnaire asks you to
describe important aspects of the university class that you are in right now, AND
how often you would **prefer** each practice to take place in your class.
There are no right or wrong answers. This is not a test and your answers will not affect your assessment. Your <u>opinion</u> is what is wanted.

2. How to Answer Each Question

On the next few pages you will find 36 sentences arranged in 6 clusters. For each sentence, circle <u>two</u> numbers, one each side, corresponding to your answers. For example:

What actually happens in this class						What you would prefer to happen in this class				
Almost always	Often	Some-times	Seldom	Almost never	**Learning**	Almost always	Often	Some-times	Seldom	Almost never
					← <u>In this class</u> … <u>In this class, I would prefer that</u> →					
5	4	3	2	1	8. The lecturer asks me questions.	5	4	3	2	1

On the left-hand side

- If you think the lecturer *almost always* asks you questions, circle the 5.
- If you think the lecturer *almost never* asks you questions, circle the 1.
- Or you can choose the number 2, 3 or 4 if one of these seems like a more accurate answer.

On the right-hand side

- If you would prefer that the lecturer *almost always* would ask you questions, circle the 5.
- If you would prefer that the lecturer *almost never* would ask you questions, circle the 1.

- Or you can choose the number 2, 3 or 4 if one of these seems like a more accurate answer.

3. How to Change Your Answer

If you want to change your answer, cross it out and circle a new number.

4. Information

Please provide information in the box below. Please be assured that your answers to this questionnaire will be treated confidentially.

Your Name: ______________________ Student number: ________________

What actually happens in this class						What I would prefer to happen in this class				
Almost always	Often	Some-times	Seldom	Almost never	**Relevance of Learning**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … / In this class, I would prefer that →					
5	4	3	2	1	1. I learn about the world outside of university.	5	4	3	2	1
5	4	3	2	1	2. My learning focuses on issues that interest me.	5	4	3	2	1
5	4	3	2	1	3. What I learn is related to my future life.	5	4	3	2	1
5	4	3	2	1	4. I learn how to solve real-life problems.	5	4	3	2	1
5	4	3	2	1	5. I learn interesting things about real life.	5	4	3	2	1
5	4	3	2	1	6. What I learn connects well with what I know already.	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never	**Reflective Thinking**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … / In this class, I would prefer that →					
5	4	3	2	1	7. I think carefully about how I learn.	5	4	3	2	1
5	4	3	2	1	8. I think critically about my own ideas.	5	4	3	2	1
5	4	3	2	1	9. I learn to be skeptical.	5	4	3	2	1
5	4	3	2	1	10. I learn how to become a better learner.	5	4	3	2	1
5	4	3	2	1	11. I think critically about my understanding.	5	4	3	2	1
5	4	3	2	1	12. I learn to suspend disbelief in new ideas.	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never	**Negotiation**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … / In this class, I would prefer that →					

5	4	3	2	1	13. I get the chance to talk to other students.	5	4	3	2	1
5	4	3	2	1	14. I discuss my experiences with other students.	5	4	3	2	1
5	4	3	2	1	15. I explain my ideas to other students.	5	4	3	2	1
5	4	3	2	1	16. I ask other students to explain their ideas.	5	4	3	2	1
5	4	3	2	1	17. Other students ask me to explain my ideas.	5	4	3	2	1
5	4	3	2	1	18. Other students explain their ideas to me.	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never		Almost always	Often	Some-times	Seldom	Almost never

What actually happens in this class						What I would prefer to happen in this class				
Almost always	Often	Some-times	Seldom	Almost never	**Leadership**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … / In this class, I would prefer that →					
5	4	3	2	1	19. The lecturer talks enthusiastically about her/his subject.	5	4	3	2	1
5	4	3	2	1	20. The lecturer holds the students' attention.	5	4	3	2	1
5	4	3	2	1	21. The lecturer is a good leader.	5	4	3	2	1
5	4	3	2	1	22. The lecturer knows everything that goes on.	5	4	3	2	1
5	4	3	2	1	23. The lecturer acts confidently.	5	4	3	2	1
5	4	3	2	1	24. The lecturer explains things clearly	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never	**Empathy**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … / In this class, I would prefer that →					
5	4	3	2	1	25. The lecturer trusts the students.	5	4	3	2	1
5	4	3	2	1	26. If students disagree with the lecturer they can talk about it.	5	4	3	2	1
5	4	3	2	1	27. The lecturer is willing to explain things again.	5	4	3	2	1
5	4	3	2	1	28. If students have something to say, the lecturer will listen.	5	4	3	2	1
5	4	3	2	1	29. The lecturer realises when students don't understand.	5	4	3	2	1

5	4	3	2	1	30. The lecturer is patient.	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never	**Support**	Almost always	Often	Some-times	Seldom	Almost never
					← In this class … In this class, I would prefer that →					
5	4	3	2	1	31. The lecturer helps students with their work.	5	4	3	2	1
5	4	3	2	1	32. The lecturer is friendly.	5	4	3	2	1
5	4	3	2	1	33. The lecturer is someone students can depend on.	5	4	3	2	1
5	4	3	2	1	34. It is all right to tell the lecturer when we do not understand.	5	4	3	2	1
5	4	3	2	1	35. The lecturer takes a personal interest in us.	5	4	3	2	1
5	4	3	2	1	36. It is a pleasant place to be.	5	4	3	2	1
Almost always	Often	Some-times	Seldom	Almost never		Almost always	Often	Some-times	Seldom	Almost never

A.1.8 Self-Monitoring and Evaluation form (SMARF)

CURTIN UNIVERSITY OF TECHNOLOGY

SCHOOL OF PHYSICAL SCIENCE

DEPARTMENT OF APPLIED PHYSICS

Self-Monitoring & Reflection Form (SMARF)

Name: ______________________ Subject: _________________________

Assessment #	**Submit date**	Collect date	**Mark**	Running average	Comment

End of semester Self- Analysis

Date: ______________________

How to use the SMARF

Carefully read the unit outline and decide on a marks goal for each of the assessment components. Enter these on the unit outline.

- Every time you submit an assessment enter the submission date in the relevant column of the SMARF.
- Every time you collect an assessment enter the collection date and mark you obtained in the relevant column of the SMARF. Then spend 30 seconds or so thinking about the outcome of that assessment and write down a comment in the relevant column. Choose comments that will help you in your next assessment or will inspire you to do more or better.

At the end of the semester compare your goal with your achievement and write a self-analysis in the space provided above.

Submit the SMARF along with your workbook for assessment.

A.1.9 Study Preferences Survey

Curtin University of Technology
Department of Applied Physics
Questionnaire on study behaviour

NAME: ______________________________________ Student No _______________________

This questionnaire asks you to estimate the average amount of time you spend per week on each of the following types of study activities for Particles and Waves 101. Do not include class time or time spent on other subjects.
The time scale is in hours with each quarter-hour marked. Put a cross to mark your time on each scale.
If you spend no time on an activity type, put a cross on the zero.

<table>
<tr><td>Activity</td><td>Time (0 - 4 hours)</td><td>*Rank</td><td>Dept use only</td></tr>
<tr><td>Reading the text-book</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>4</td></tr>
<tr><td>Rewriting or copying out lecture notes</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>5</td></tr>
<tr><td>Writing answers to assignment questions</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>6</td></tr>
<tr><td>Doing extra problems from the text-book or elsewhere</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>7</td></tr>
<tr><td>Summarising sections from the text-book</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>8</td></tr>
<tr><td>Discussing your work with a lecturer or tutor</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>9</td></tr>
<tr><td>Discussing your work with friends or work partners</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>10</td></tr>
<tr><td>Writing up practical reports</td><td>0----|-----|-----|-----1----|-----|-----|-----2----|-----|-----|-----3----|-----|-----|-----4---→</td><td></td><td>11</td></tr>
</table>

Just thinking about the physics on your own (and not at the same time as doing any of the above)	0----|-----|-----|-----1-----|-----|-----|-----2-----|-----|-----|-----3-----|-----|-----|-----4--- →		12
Reading physics that is not directly related to any of your class-work.	0----|-----|-----|-----1-----|-----|-----|-----2-----|-----|-----|-----3-----|-----|-----|-----4--- →		13
Working with an external tutor or helper.	0----|-----|-----|-----1-----|-----|-----|-----2-----|-----|-----|-----3-----|-----|-----|-----4--- →		14
#	0----|-----|-----|-----1-----|-----|-----|-----2-----|-----|-----|-----3-----|-----|-----|-----4--- →		15

Please add any other relevant activities to this list, together with your time estimate.
* In the last column, number each activity you do in order of most important to least important in terms of learning physics FOR YOU. Number 1 means of most importance.

Thank you for completing the questionnaire.

A.1.10 Exit survey

Curtin University of Technology

Dept. of Applied Physics

Dear

I understand that you have recently withdrawn from the Particles and Waves 101 unit. As part of my research in physics learning, I am interested in the reasons why students such as yourself withdraw from this physics unit. Your experience is important in helping us to better understand the needs of our students.

If you can spare a few minutes, please complete the following brief questionnaire and return it in the enclosed stamped, addressed envelope.

1. How many <u>first semester</u> credit points did you enrol for at the start of the year? (please circle the number)

74 or less	1
75 - 99	2
100 - 120	3
more than 120	4

2. Have you withdrawn just from just Particles and Waves 101 or from your whole course?

(please circle the number)

P & W 101 only	1
Whole course	2

3. For how many weeks did you attend classes? ________________

4. Do you intend to re-enrol again next year? (please circle the number)

yes	1
no	2
undecided	3
	4

5. On the back of this page is a list of *reasons* which students often give when they need to drop one or more units.

What to do:

In the first blank column, tick ANY statements that apply to you.

If you have a reason that <u>is not listed</u>, add it to the bottom of the list and tick it.

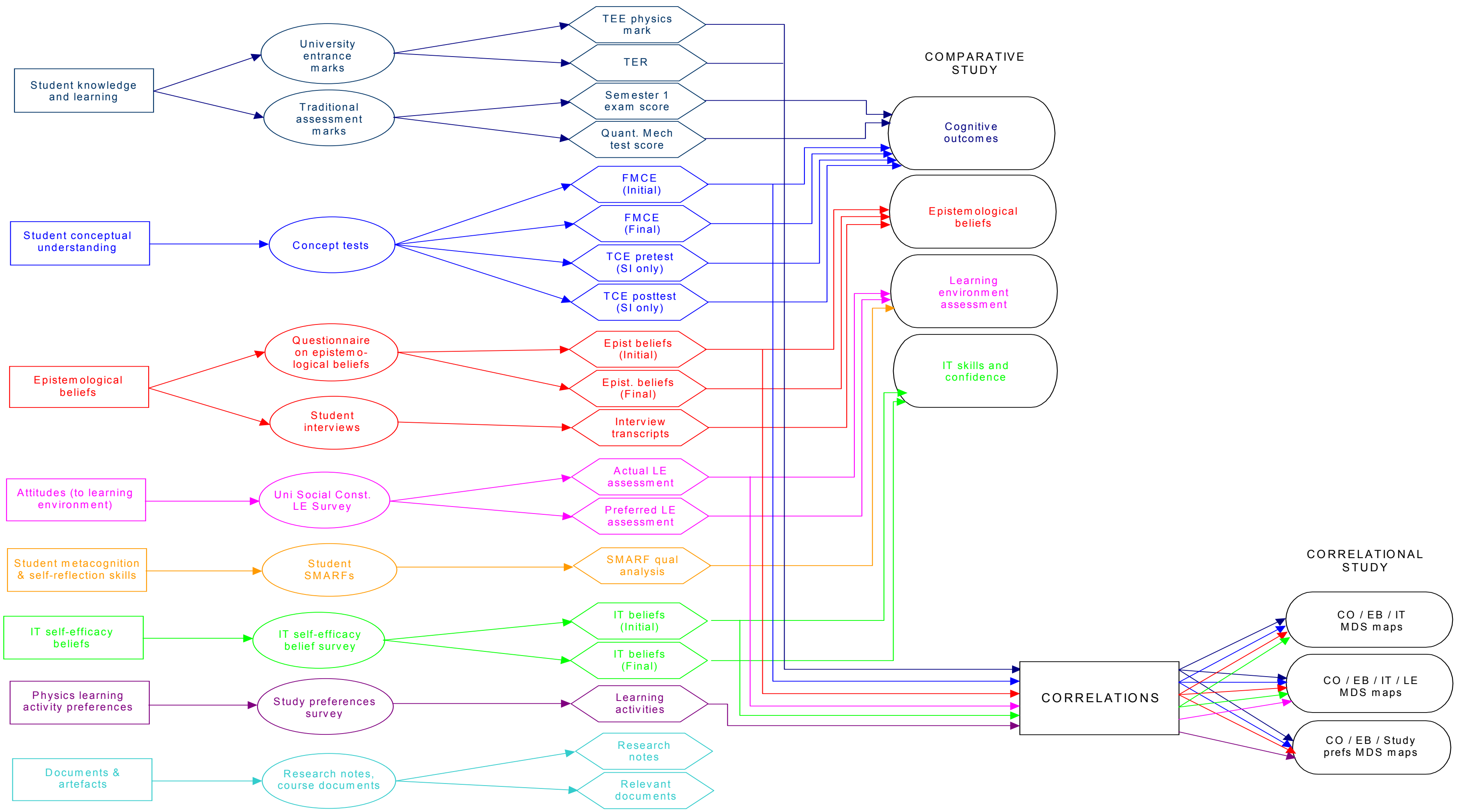
Indicate the *relative importance* of your reasons by putting a percentage against each reason you ticked. The percentages should add to 100.

REASONS	tick here	%
I chose to withdraw because I applied for, and got, a job.		
I had to withdraw because I needed to get a job.		
I had to withdraw because of personal ill health.		
I had to withdraw for family-related reasons.		
I withdrew because I changed jobs and the hours make it difficult to get to classes.		
I withdrew because I found 'Particles & Waves' too difficult.		
I withdrew because I found that 'Particles and Waves' was not challenging or difficult enough.		
I withdrew because I did not like the way 'Particles & Waves' was being taught.		
I withdrew from 'Particles & Waves' because I feel I did not get on well with my lecturer / tutor / lab demonstrator.		
I was coping with 'Particles & Waves' but withdrew because the work load for the unit was too great.		
I understood the work in lectures but withdrew because the 'Particles & Waves' assignments were too hard.		
I withdrew from 'Particles & Waves' because I did not know, or get to know, anyone else in the class.		
I withdrew from 'Particles & Waves' because I did not know where to go to get help with problems.		

Thank you for taking the time to complete this survey.
(Shelley Yeo - Physics Education Research and Development Group)

A.2 Data

A.2.1 Flow chart of data sources and use



A.2.2 Syllabus Unit Outlines

Curtin University of Technology
School of Physical Sciences

Department of Applied Physics

PARTICLES AND WAVES 101 (Studio Classes)
Unit Outline - SEMESTER 1, 1999

Unit Index No:	01737 This is a SIGNIFICANT UNIT (Failing twice may lead to termination of your course)
Credit points:	15
Pre-requisites:	TEE Physics, TEE Calculus and Applicable Maths. If Applicable Maths only, then calculus bridging course is recommended.

ORGANISATION
Students should attend one 3 hour workshop per week in the STUDIO 301.233

	Day	**Time**
Physics/MultiDisc/Double Degree	Monday	14:00 - 17:00
Geophysics	Tuesday	10:00 - 13:00

SCHEDULE
The studio instruction mode requires that you spend 3 hours per week in a formal class. Depending on your abilities, to succeed in this unit you should allow **at least 4 hours per week** of additional work outside formal classes, some of which may require that you use the Studio. Approximately 1 to 2 of these hours per week should be spent on reading the text and note making, 1 to 2 hours on assignments and problem solving. Remember this workload is a **minimum** - if you do less during the first few weeks of semester, it will be very difficult to catch up. If you are not working at this intensity from day 1 of semester, you are not working at a professional enough level. Later in the semester you should also add an additional hour for exam preparation.

WHAT IF I HAVE QUESTION OR PROBLEM
1. Your first stop should be the STUDIO where there is a chance that you will find another student who can help.
2. If not, then you can try your tutor. If you cannot find your tutor then you should try emailing your instructor or fellow students.
3. If it is really urgent you can telephone your instructor. Most instructors have answering machines - please leave a detailed message and a contact phone number.
4. Any questions regarding other matters, such as course organisation, study program or excessive workload should be brought to the subject co-ordinator.

TEXTBOOK:
Serway, Physics for Scientists and Engineers, Fourth edition, with modern Physics .
REFERENCES:
These are listed in the Syllabus Outline below. Note there is no need to purchase these as they will be available from the Closed Reserve Section of the Library.

ASSESSMENT: The final mark for the course will be made up as follows:

	Total	My Goal is
Mid term tests	20%	____
Assignments	15%	____
Work Book and SMARF	10%	____
Final examination	55%	____
TOTAL	**100%**	____

ASSIGNMENTS
Weekly tutorial problems will be handed out during the STUDIO workshop. Some of these will be **compulsory** and must be handed **by 9:00 am the following Monday**. Marks obtained for these problems contribute 15% of your final mark for the course. *Your* solutions must be placed in the pigeon holes (your tutor's name will be clearly labelled) outside the first year laboratory room 301.119. Any plagiarism may result in 0 % being awarded to **all** students involved. Students must include their names, student numbers, tutor's name, tutorial group and unit [P&W 101, Studio] on their work. Loose sheets **must** be stapled together. **Late assignments may be given 0%**.
TESTS
During the semester there will be 2 tests (worth 10 % each) taking about 50 mins each. The first will be test in April, based on the first half of semester's work and the second half will be tested in May.
FINAL EXAMINATION:
The final examination will consist of a two hour paper held during the formal examination period, 14 -25 June 1999, and will be based on any of the material listed in the syllabus even if it is not specifically covered in class. Failure to complete fully the test and assignment requirements, or a mark of less than 40% in the final examination, may lead to the award of an F (FAIL) grade, irrespective of the total marks gained. Students will be advised of any particular conditions regarding the final exam paper prior to the examination. Copies of past exam papers are available in the Library and are available on the World Wide Web.
WORK BOOK & SMARF
All of your own or team work (summaries, handouts, notes, problems and questions, assignments) are to be retained by you and submitted at the end of the semester. It should be well organised (i.e. table of contents and page numbers or sections etc.). Any combination of paper and/or electronic form is possible. Soft cover lecture books (with or without perforated pages) are unacceptable. Suitability of particular formats will be discussed and periodic checks will be done in class. You **must** submit your work book for assessment **within 24 hours of the final exam** for this unit to obtain credit for it. It is your responsibility to keep appropriate backups of ALL materials especially floppy discs. It is strongly recommended that you make copies of important paper materials and store these - just in case. No workbook - No Marks. The SMARF is explained on the last page of this outline

SUPPLEMENTARY EXAMINATIONS
All supplementary examinations offered by the School of Physical Sciences will be held in the **week 12-16 July, 1999**. Supplementary examinations *will not* be available at any other time. Students will be notified by letter from the School of Physical Sciences (**make sure that the University is aware of any changes in your address - this is your responsibility**). Students who will not be in the metropolitan area during that week must contact School's Administrative Assistant, Ms J. Talbot (9266 7539) immediately and arrange for a suitable invigilator (to be arranged by the student, but approved by the School of Physical Sciences).

EMAIL
You are expected to check your email everyday you come to Curtin. Email will be used for a variety of tasks including to send out instructions, for testing purposes, for surveys and discussion between students. You can also email you instructor for help (preferably not the night before assignments are due). Eventually we will also use email for submission of documents.

CLASS REPRESENTATIVE: The class is to elect 2 representatives to liase with the instructors on any issues related to the unit, e.g. suggestions for improvement, work load, assessment, etc.

ENROLMENT AND HECS
Your enrolment with the University is fixed by sending you an ENROLMENT ADVICE and by you meeting specified requirements. You can make requests to have corrections made to your enrolment Semester 1, 1998 up to Fri 5 March 1999 for additions and up to 26 March 1999 for withdrawals irrespective of whether you have received or verified your enrolment advice by then. It is up to you. The University will not change records after March. HECS liabilities where they apply and your results depend on your 26 March enrolment. Withdrawals made after this date will not reduce your HECS liability.

To ensure that all the units that you are interested in for **SECOND Semester** will be offered, you **MUST** enrol for all second semester units **before** March 26. Your HECS liability for Second Semester will be determined by your enrolment status in August and you will be able to withdraw from second Semester units up to that time.

Dr M G Zadnik, Unit Co-ordinator, Office #301.123,
Tel: 9266 2326, email address: m.zadnik@curtin.edu.au

and
Ms Shelley Yeo, Office #301.231
Tel: 9266 3785, email address: ryeosr@cc.curtin.edu.au

Dr Craig Buckley, Office #301.212A
Tel: 9266 3532, email address: rbuckley@cc.curtin.edu.au

PARTICLES AND WAVES 101 - SEMESTER 1, 1999

TEXT BOOK: Serway "Physics for Scientists and Engineers" Fourth Edition.

REFERENCES: Halliday, Resnick and Walker "Fundamentals of Physics"
(Fourth Edition, Extended)
Giancoli "General Physics"
Ohanian "Physics"
Feynman, Leighton & Sands "Lectures on Physics Vol 1"

STUDIO WEEKLY PROGRAM

SYSTEMS OF PARTICLES

Review of linear Mechanics

1. Measurement, vectors and scalars, resolution, addition and multiplication of vectors, Ch1,2, 3.

2. Applications of vectors to problems in Physics: two dimensional motion under gravity. Ch 4.
   Force and Newton's Laws. Ch 5.
   Uniform circular motion. Ch 6.

3. Conservation of energy, work and energy. Chs 7, 8.

4. Conservation of momentum and collisions in one and two dimensions. Ch 9.

Rotational Mechanics

5. Rotating bodies, rotational variables, equations of motion for constant angular acceleration. Kinetic energy of rotation, moment of inertia. Ch 10.

6. Torque, rolling motion, angular momentum and precession. Ch 11.

GRAVITATION

7. Gravitation, gravitational fields, action at a distance, force acting along a line joining the centres of mass. Gravitational measurements. Ch 14.

VIBRATIONS

8. Elasticity, Hooke's Law, SHM. Ch 12.

9. Harmonic oscillator, energy of SHM. Resonance, damped harmonic motion, forced oscillations. Ch 13.

WAVES

10. Mechanical waves, travelling waves, wave equation. Power and intensity in wave motion. Ch 16. All of this Chapter is relevant except § 16.9.

11. Superposition, interference. Standing waves, resonance. Beats, complex waves Ch 18. All of this Chapter is important but DETAILS of §§18.5 & 18.6 are NOT required.

12. Doppler effect. Ch 17. Detailed and quantitative understanding of §§17.2 and 17.3 will NOT be required.

13. Electromagnetic waves and spectrum, polarisation. Ch 34, Ch 38.

14. Interference of light. Young's 2 slit experiment. Ch 37. All of this Chapter is relevant except § 37.7. Also § 35.6.

15. Resolution. Diffraction by a single, double and multiple slits. Ch 38.

CURTIN UNIVERSITY OF TECHNOLOGY
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF APPLIED PHYSICS

STRUCTURE of MATTER 102 (STUDIO CLASSES)
Unit Index No: 01744

TENTATIVE STUDENT INFORMATION SHEET SEMESTER 2, 1999

This Document only applies to students taking this unit in the Physics Studio.

This unit is a significant unit. Failing it twice may lead to termination of your course.

Credit points: 15
Pre-requisites: TEE Physics, TEE Calculus and Applicable Maths. If Applicable Maths only, then a calculus bridging course is recommended.

FORMAL CLASS SCHEDULE
Students should attend one 2 hr workshop per week in Room 301.233

	Day	*Times*
Physics/MultiDisc	Tuesday	9.00 - 11.00
Geophysics	Tuesday	14:00-16:00

SCHEDULE
The studio instruction mode only requires that you spend 2 hours per week in formal classes. Depending on your abilities, you should allow **at least** 4 hours per week of additional work for this unit some of which may require that you use the Studio. **Approximately 1 to 2 hrs per week should be spent on reading the text and note making**, 1 to 3 hrs on assignments and problem solving. Remember this is a **minimum** - if you fall behind **it will be almost impossible to catch up**.
Later in the semester you should also add an additional hour for exam preparation.

TEXTBOOKS:
Serway, R. A., *Physics for Scientists and Engineers* (4th Ed., with Modern Physics).
(The 3rd Ed. will be adequate but chapter & problem numbers may differ).

REFERENCES (NOT to be purchased) (held in Reserve):
Halliday, Resnick and Walker, *Fundamentals of Physics*, 4th Ed., Extended.
Giancoli, *Physics*
Ohanian, *Physics*
Feynman, Leighton & Sands, *Lectures on Physics, Vol. 1*

ASSIGNMENTS
Weekly assignment problems will be handed out during the studio workshops. Some of these problems will be **compulsory** and must be handed in for marking by **12:00 noon the following Monday**. Marks obtained for these problems contribute 20% of your final mark for the course. *Your* solutions must be placed in the pigeon holes (labelled with your tutor's name) outside the first year laboratory room 301.119. Any plagiarism may result in 0 % being awarded to **all** students involved. ***Students must include their name, student number, tutor's name, date and unit [SoM 102 (studio)] on their work. Loose sheets must be stapled together. Late assignments will be given 0%.***
Solutions to the previous week's problems will be posted on the first year notice board opposite laboratory room 301.128.

TESTS
During the semester, in the workshop times there will be 2 tests (~50 min duration). Total contribution to final mark, 20%.

WORK BOOK
All of your own or team work (notes, problems and questions, assignments, experimental data and observations, etc) is to be retained and submitted at the end of the semester. How you do this is up to you but it should be well organized (ie table of contents and page numbers or sections etc). Any combination of paper and/or electronic form is possible. Soft cover lecture books (with or without perforated pages) are unacceptable.

At the end of semester you should submit your work book for assessment.
You need to submit your work book for assessment **within 24 hours of the final exam for this uni**t. It is your reponsibility to keep appropriate backups of any materials especially floppy discs. It is strongly recommended that you photocopy paper materials and store these - just in case. No workbook - No Marks.

ASSESSMENT

The final mark for the course will be made up as follows:

Mid term tests	20%
Assignments	20%
Work Book and summaries	10%
Final examination	50%
TOTAL	**100%**

FINAL EXAMINATION
The final examination will consist of a two hour paper held during the formal examination period (15 - 26 November) and will be based on any of the material listed in the syllabus **even if it is not specifically covered in class**. A mark of 40% or less in the final examination may lead to the award of an F (FAIL) grade, irrespective of the total mark gained. Students will be advised of any particular conditions regarding the final exam paper prior to the examination. Copies of past exam papers are available in the Library and will soon be available on the World Wide Web.

SUPPLEMENTARY EXAMINATIONS
All supplementary examinations offered by the School of Physical Sciences will be held in the week 13 -17 December. Supplementary examinations *will not* be available at any other time. Students will be notified by letter to the address supplied to the School (**make sure that the School is aware of any changes in your address - this is your responsibility**). Students who will not be in the metropolitan area during that week must contact the School's Administrative Officer, (9266 7539) or the Departmental Secretary (9266 7192) immediately upon receipt of the offer, to arrange for a suitable invigilator.

ENROLMENT AND HECS
Your enrolment with the university is fixed by sending you an ENROLMENT ADVICE and by you meeting specified requirements. You can make requests to have corrections made to your enrolment up to August 6 (additions) or August 31 (withdrawals).
NOTE however that your second Semester **HECS** liabilities (where they apply) depend on your August 31, 1999 enrolment. Withdrawals made after August 31 will **NOT** reduce your HECS liability or your Student Guild Fee.

EMAIL
You are expected to check your email everyday you come to Curtin. Email will be used for a variety of tasks including to send out instructions, for testing purposes, for surveys and discussion between students. You can also email your instructor for help (preferably not the night before assignments are due).

CLASS REPRESENTATIVE: The class is to elect 2 representatives to liase with the instructors on any issues related to the unit, e.g. suggestions for improvement, work load, assessment, etc.

ENQUIRIES
Any questions or problems with the course material should be referred to your lecturers. Any questions regarding other matters, such as course organisation, study program or workload should be brought to the subject coordinator.

Dr M G Zadnik, Unit Co-ordinator, Office #301.123,
Tel: 9266 2326, email address: m.zadnik@curtin.edu.au

and
Ms Shelley Yeo, Office #301.231
Tel: 9266 3785, email address: ryeosr@alpha2.curtin.edu.au

Dr Craig Buckley, Office #301.212A
Tel: 9266 3532, email address: rbuckley@cc.curtin.edu.au

CURTIN UNIVERSITY OF TECHNOLOGY
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF APPLIED PHYSICS

STRUCTURE of MATTER 102 - STUDIO Course

SYLLABUS OUTLINE

TEXT BOOK: Serway, *Physics for Scientists and Engineers*, 4th Ed.

REFERENCES:

Halliday, Resnick and Walker, *Fundamentals of Physics*, 4th Ed., Extended.
Giancoli, *Physics*
Ohanian, *Physics*
Feynman, Leighton & Sands, *Lectures on Physics, Vol. 1*

THERMODYNAMICS, Chapters 19 to 22

Temperature & kinetic energy, Thermometers, Zeroth Law of TD, Thermal Expansion

Heat and the First Law of TD, Heat Capacity and Specific heat, Latent Heat

Kinetic Theory of Gases, Specific heat of an ideal gas, Adaibatic processes, Equipartition of energy, Distribution of Molecular speeds, Mean free path , Van der Waal's Eqn

Heat Engines, Entropy and the Second Law of TD, reversible and non-reversible processes, Heat pumps and refrigerators

SPECIAL RELATIVITY, Chapter 39

Kinematics:
Galilean transformations, relative motion velocity of light.
Special Theory of Relativity
Michelson-Morley experiment
Simultaneity, time dilation, the twin paradox.
Length contraction, the Lorentz transform's, Four-dimensional space-time
Relativistic mass, mass and energy.
Doppler effect, the expanding universe, general relativity, black holes.

QUANTUM PHYSICS Chapters 40 to 42

Thermal Radiation
Photoelectric effect
Compton effect
Bohr's model of the hydrogen atom
Atomic spectra
Double slit experiement, Uncertainty Principle
Schrodinger's Eqn
Quantum tunneling, Scanning Tunneling Microscope
Wave functions
Probability density
Quantum numbers
The Hydrogen atom
Exclusion Principle and The Periodic Table

A.2.3 Correlation data

Table A.1. Correlations among SI students' initial epistemological beliefs, cognitive status and IT skill & confidence.

Correlations

		TEE physics mark	TER	FMCE pretest score	Perceived IT skill (initial)	IT confidence (initial)	FAQLPRE	SKPRE	CKPRE	EAPRE
TEE physics mark	Pearson Correlation	1.000	.836**	.584**	.251	.165	.022	-.320*	.199	.096
	Sig. (2-tailed)	.	.000	.000	.123	.315	.893	.044	.218	.555
	N	40	32	38	39	39	40	40	40	40
TER	Pearson Correlation	.836**	1.000	.584**	.382*	.255	.058	-.413*	.555**	-.027
	Sig. (2-tailed)	.000	.	.000	.031	.159	.755	.019	.001	.884
	N	32	33	32	32	32	32	32	32	32
FMCE pretest score	Pearson Correlation	.584**	.584**	1.000	.365*	.104	.163	-.201	.300	.107
	Sig. (2-tailed)	.000	.000	.	.019	.516	.302	.202	.054	.500
	N	38	32	42	41	41	42	42	42	42
Perceived IT skill (initial)	Pearson Correlation	.251	.382*	.365*	1.000	-.245	-.074	.131	.273	.150
	Sig. (2-tailed)	.123	.031	.019	.	.110	.637	.402	.077	.337
	N	39	32	41	44	44	43	43	43	43
IT confidence (initial)	Pearson Correlation	.165	.255	.104	-.245	1.000	.102	-.186	-.037	.061
	Sig. (2-tailed)	.315	.159	.516	.110	.	.514	.233	.812	.698
	N	39	32	41	44	44	43	43	43	43
FAQLPRE	Pearson Correlation	.022	.058	.163	-.074	.102	1.000	-.039	-.077	-.298*
	Sig. (2-tailed)	.893	.755	.302	.637	.514	.	.804	.622	.049
	N	40	32	42	43	43	44	44	44	44
SKPRE	Pearson Correlation	-.320*	-.413*	-.201	.131	-.186	-.039	1.000	.077	.238
	Sig. (2-tailed)	.044	.019	.202	.402	.233	.804	.	.619	.120
	N	40	32	42	43	43	44	44	44	44
CKPRE	Pearson Correlation	.199	.555**	.300	.273	-.037	-.077	.077	1.000	.052
	Sig. (2-tailed)	.218	.001	.054	.077	.812	.622	.619	.	.739
	N	40	32	42	43	43	44	44	44	44
EAPRE	Pearson Correlation	.096	-.027	.107	.150	.061	-.298*	.238	.052	1.000
	Sig. (2-tailed)	.555	.884	.500	.337	.698	.049	.120	.739	.
	N	40	32	42	43	43	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table A.2. Correlations among TI students' initial epistemological beliefs, cognitive status and IT skill & confidence.

Correlations

		TEE physics mark	TER	FMCE pretest score	Perceived IT skill (initial)	IT confidence (initial)	FAQLPRE	SKPRE	CKPRE	EAPRE
TEE physics mark	Pearson Correlation	1.000	.670**	.466**	.116	.242	.027	-.161	-.164	-.152
	Sig. (2-tailed)	.	.000	.000	.367	.056	.829	.205	.195	.230
	N	64	56	63	63	63	64	64	64	64
TER	Pearson Correlation	.670**	1.000	.436**	-.082	.160	-.024	-.139	-.120	-.114
	Sig. (2-tailed)	.000	.	.001	.543	.234	.857	.298	.368	.395
	N	56	58	57	57	57	58	58	58	58
FMCE pretest score	Pearson Correlation	.466**	.436**	1.000	.048	-.044	.315**	-.245*	.016	-.214
	Sig. (2-tailed)	.000	.001	.	.699	.720	.008	.042	.897	.078
	N	63	57	69	68	68	69	69	69	69
Perceived IT skill (initial)	Pearson Correlation	.116	-.082	.048	1.000	-.127	.192	.034	.204	-.173
	Sig. (2-tailed)	.367	.543	.699	.	.300	.113	.779	.093	.156
	N	63	57	68	69	69	69	69	69	69
IT confidence (initial)	Pearson Correlation	.242	.160	-.044	-.127	1.000	.007	-.199	-.117	-.021
	Sig. (2-tailed)	.056	.234	.720	.300	.	.955	.101	.337	.863
	N	63	57	68	69	69	69	69	69	69
FAQLPRE	Pearson Correlation	.027	-.024	.315**	.192	.007	1.000	-.089	-.036	-.256*
	Sig. (2-tailed)	.829	.857	.008	.113	.955	.	.465	.769	.032
	N	64	58	69	69	69	70	70	70	70
SKPRE	Pearson Correlation	-.161	-.139	-.245*	.034	-.199	-.089	1.000	.203	-.124
	Sig. (2-tailed)	.205	.298	.042	.779	.101	.465	.	.091	.305
	N	64	58	69	69	69	70	70	70	70
CKPRE	Pearson Correlation	-.164	-.120	.016	.204	-.117	-.036	.203	1.000	-.127
	Sig. (2-tailed)	.195	.368	.897	.093	.337	.769	.091	.	.295
	N	64	58	69	69	69	70	70	70	70
EAPRE	Pearson Correlation	-.152	-.114	-.214	-.173	-.021	-.256*	-.124	-.127	1.000
	Sig. (2-tailed)	.230	.395	.078	.156	.863	.032	.305	.295	.
	N	64	58	69	69	69	70	70	70	70

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table A 3. Correlations among SI students' final epistemological beliefs, cognitive outcomes and IT skill & confidence.

Correlations

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST
Semester 1 exam score	Pearson Correlation	1.000	.622**	.521**	-.033	.139	-.057	-.327*	.050	-.154
	Sig. (2-tailed)	.	.000	.000	.831	.367	.712	.028	.745	.314
	N	45	43	42	44	44	45	45	45	45
Quantum Mechanics test score	Pearson Correlation	.622**	1.000	.465**	.006	.120	-.087	-.385*	.048	-.278
	Sig. (2-tailed)	.000	.	.002	.970	.450	.581	.011	.762	.072
	N	43	43	42	42	42	43	43	43	43
FMCE posttest score	Pearson Correlation	.521**	.465**	1.000	.231	.116	.013	-.275	.074	-.267
	Sig. (2-tailed)	.000	.002	.	.147	.470	.933	.078	.639	.087
	N	42	42	42	41	41	42	42	42	42
Perceived IT skill (final)	Pearson Correlation	-.033	.006	.231	1.000	.235	-.100	-.090	.017	.204
	Sig. (2-tailed)	.831	.970	.147	.	.124	.518	.560	.913	.184
	N	44	42	41	44	44	44	44	44	44
IT confidence (final)	Pearson Correlation	.139	.120	.116	.235	1.000	.156	.181	.037	.038
	Sig. (2-tailed)	.367	.450	.470	.124	.	.310	.239	.813	.804
	N	44	42	41	44	44	44	44	44	44
FAQLPOST	Pearson Correlation	-.057	-.087	.013	-.100	.156	1.000	.209	.112	-.351*
	Sig. (2-tailed)	.712	.581	.933	.518	.310	.	.168	.466	.018
	N	45	43	42	44	44	45	45	45	45
SKPOST	Pearson Correlation	-.327*	-.385*	-.275	-.090	.181	.209	1.000	-.070	.028
	Sig. (2-tailed)	.028	.011	.078	.560	.239	.168	.	.646	.858
	N	45	43	42	44	44	45	45	45	45
CKPOST	Pearson Correlation	.050	.048	.074	.017	.037	.112	-.070	1.000	-.072
	Sig. (2-tailed)	.745	.762	.639	.913	.813	.466	.646	.	.638
	N	45	43	42	44	44	45	45	45	45
EAPOST	Pearson Correlation	-.154	-.278	-.267	.204	.038	-.351*	.028	-.072	1.000
	Sig. (2-tailed)	.314	.072	.087	.184	.804	.018	.858	.638	.
	N	45	43	42	44	44	45	45	45	45

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table A.4. Correlations among TI students' final epistemological beliefs, cognitive outcomes and IT skill & confidence.

Correlations

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST
Semester 1 exam score	Pearson Correlation	1.000	.362**	.673**	.059	.099	-.115	-.140	-.290*	-.192
	Sig. (2-tailed)	.	.003	.000	.662	.461	.389	.293	.027	.148
	N	68	67	63	58	58	58	58	58	58
Quantum Mechanics test score	Pearson Correlation	.362**	1.000	.421**	.187	.077	.102	-.170	-.146	-.144
	Sig. (2-tailed)	.003	.	.001	.156	.563	.443	.199	.269	.277
	N	67	69	64	59	59	59	59	59	59
FMCE posttest score	Pearson Correlation	.673**	.421**	1.000	.000	.004	.054	-.209	.010	-.111
	Sig. (2-tailed)	.000	.001	.	.997	.978	.693	.122	.943	.415
	N	63	64	65	56	56	56	56	56	56
Perceived IT skill (final)	Pearson Correlation	.059	.187	.000	1.000	.166	.179	-.245	.027	.099
	Sig. (2-tailed)	.662	.156	.997	.	.204	.171	.059	.835	.450
	N	58	59	56	60	60	60	60	60	60
IT confidence (final)	Pearson Correlation	.099	.077	.004	.166	1.000	.068	-.332**	.021	.039
	Sig. (2-tailed)	.461	.563	.978	.204	.	.606	.009	.876	.765
	N	58	59	56	60	60	60	60	60	60
FAQLPOST	Pearson Correlation	-.115	.102	.054	.179	.068	1.000	.120	.203	-.047
	Sig. (2-tailed)	.389	.443	.693	.171	.606	.	.362	.120	.724
	N	58	59	56	60	60	60	60	60	60
SKPOST	Pearson Correlation	-.140	-.170	-.209	-.245	-.332**	.120	1.000	.228	-.248
	Sig. (2-tailed)	.293	.199	.122	.059	.009	.362	.	.080	.056
	N	58	59	56	60	60	60	60	60	60
CKPOST	Pearson Correlation	-.290*	-.146	.010	.027	.021	.203	.228	1.000	.087
	Sig. (2-tailed)	.027	.269	.943	.835	.876	.120	.080	.	.509
	N	58	59	56	60	60	60	60	60	60
EAPOST	Pearson Correlation	-.192	-.144	-.111	.099	.039	-.047	-.248	.087	1.000
	Sig. (2-tailed)	.148	.277	.415	.450	.765	.724	.056	.509	.
	N	58	59	56	60	60	60	60	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table A.5. Correlations among SI students' final EBs, COs, IT measures and Actual LE attitudes.

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST	Relevance (actual)	Reflection (actual)	Negotiation (actual)	Leadership (actual)	Empathy (actual)	Support (actual)
Semester 1 exam score	Pearson Correlation	1.000	.622	.521	-.033	.139	-.057	-.327	.050	-.154	-.187	.041	-.175	-.338	-.249	-.244
	Sig. (2-tailed)	.	.000	.000	.831	.367	.712	.028	.745	.314	.269	.808	.299	.041	.137	.145
	N	45	43	42	44	44	45	45	45	45	37	37	37	37	37	37
Quantum Mechanics test score	Pearson Correlation	.622	1.000	.465	.006	.120	-.087	-.385	.048	-.278	-.126	-.020	.051	-.337	-.345	-.306
	Sig. (2-tailed)	.000	.	.002	.970	.450	.581	.011	.762	.072	.471	.910	.770	.048	.043	.074
	N	43	43	42	42	42	43	43	43	43	35	35	35	35	35	35
FMCE posttest score	Pearson Correlation	.521	.465	1.000	.231	.116	.013	-.275	.074	-.267	-.146	.221	.006	-.286	-.170	-.076
	Sig. (2-tailed)	.000	.002	.	.147	.470	.933	.078	.639	.087	.409	.209	.971	.101	.335	.667
	N	42	42	42	41	41	42	42	42	42	34	34	34	34	34	34
Perceived IT skill (final)	Pearson Correlation	-.033	.006	.231	1.000	.235	-.100	-.090	.017	.204	.126	.133	.232	.203	.129	.115
	Sig. (2-tailed)	.831	.970	.147	.	.124	.518	.560	.913	.184	.465	.440	.174	.234	.454	.503
	N	44	42	41	44	44	44	44	44	44	36	36	36	36	36	36
IT confidence (final)	Pearson Correlation	.139	.120	.116	.235	1.000	.156	.181	.037	.038	-.051	.132	.088	-.080	-.138	-.083
	Sig. (2-tailed)	.367	.450	.470	.124	.	.310	.239	.813	.804	.766	.443	.611	.644	.422	.629
	N	44	42	41	44	44	44	44	44	44	36	36	36	36	36	36
FAQLPOST	Pearson Correlation	-.057	-.087	.013	-.100	.156	1.000	.209	.112	-.351	-.159	-.012	-.354	-.403	.043	-.022
	Sig. (2-tailed)	.712	.581	.933	.518	.310	.	.168	.466	.018	.347	.943	.032	.013	.802	.898
	N	45	43	42	44	44	45	45	45	45	37	37	37	37	37	37
SKPOST	Pearson Correlation	-.327	-.385	-.275	-.090	.181	.209	1.000	-.070	.028	-.291	-.056	.063	-.174	-.250	-.130
	Sig. (2-tailed)	.028	.011	.078	.560	.239	.168	.	.646	.858	.081	.740	.713	.304	.136	.445
	N	45	43	42	44	44	45	45	45	45	37	37	37	37	37	37
CKPOST	Pearson Correlation	.050	.048	.074	.017	.037	.112	-.070	1.000	-.072	.058	.090	-.304	-.013	-.060	-.093
	Sig. (2-tailed)	.745	.762	.639	.913	.813	.466	.646	.	.638	.734	.598	.068	.941	.724	.582
	N	45	43	42	44	44	45	45	45	45	37	37	37	37	37	37
EAPOST	Pearson Correlation	-.154	-.278	-.267	.204	.038	-.351	.028	-.072	1.000	.084	-.331	.171	.560	.127	.123
	Sig. (2-tailed)	.314	.072	.087	.184	.804	.018	.858	.638	.	.622	.045	.311	.000	.456	.469
	N	45	43	42	44	44	45	45	45	45	37	37	37	37	37	37
Relevance (actual)	Pearson Correlation	-.187	-.126	-.146	.126	-.051	-.159	-.291	.058	.084	1.000	.029	.176	.578	.436	.555
	Sig. (2-tailed)	.269	.471	.409	.465	.766	.347	.081	.734	.622	.	.869	.303	.000	.008	.000
	N	37	35	34	36	36	37	37	37	37	37	36	36	36	36	36
Reflection (actual)	Pearson Correlation	.041	-.020	.221	.133	.132	-.012	-.056	.090	-.331	.029	1.000	-.010	-.253	-.073	.011
	Sig. (2-tailed)	.808	.910	.209	.440	.443	.943	.740	.598	.045	.869	.	.954	.137	.674	.950
	N	37	35	34	36	36	37	37	37	37	36	37	36	36	36	36
Negotiation (actual)	Pearson Correlation	-.175	.051	.006	.232	.088	-.354	.063	-.304	.171	.176	-.010	1.000	.121	-.004	.051
	Sig. (2-tailed)	.299	.770	.971	.174	.611	.032	.713	.068	.311	.303	.954	.	.481	.981	.767
	N	37	35	34	36	36	37	37	37	37	36	36	37	36	36	36
Leadership (actual)	Pearson Correlation	-.338	-.337	-.286	.203	-.080	-.403	-.174	-.013	.560	.578	-.253	.121	1.000	.647	.683
	Sig. (2-tailed)	.041	.048	.101	.234	.644	.013	.304	.941	.000	.000	.137	.481	.	.000	.000
	N	37	35	34	36	36	37	37	37	37	36	36	36	37	37	37
Empathy (actual)	Pearson Correlation	-.249	-.345	-.170	.129	-.138	.043	-.250	-.060	.127	.436	-.073	-.004	.647	1.000	.903
	Sig. (2-tailed)	.137	.043	.335	.454	.422	.802	.136	.724	.456	.008	.674	.981	.000	.	.000
	N	37	35	34	36	36	37	37	37	37	36	36	36	37	37	37
Support (actual)	Pearson Correlation	-.244	-.306	-.076	.115	-.083	-.022	-.130	-.093	.123	.555	.011	.051	.683	.903	1.000
	Sig. (2-tailed)	.145	.074	.667	.503	.629	.898	.445	.582	.469	.000	.950	.767	.000	.000	.
	N	37	35	34	36	36	37	37	37	37	36	36	36	37	37	37

Table A.6. Correlations among TI students' final EBs, COs, IT measures and Actual LE attitudes.

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST	Relevance (actual)	Reflection (actual)	Negotiation (actual)	Leadership (actual)	Empathy (actual)	Support (actual)
Semester 1 exam score	Pearson Correlation	1.000	.362	.673	.059	.099	-.115	-.140	-.290	-.192	-.023	.164	-.058	-.138	-.019	-.007
	Sig. (2-tailed)	.	.003	.000	.662	.461	.389	.293	.027	.148	.863	.224	.663	.301	.891	.957
	N	68	67	63	58	58	58	58	58	58	57	57	58	58	57	57
Quantum Mechanics test score	Pearson Correlation	.362	1.000	.421	.187	.077	.102	-.170	-.146	-.144	.065	.259	-.151	-.158	-.143	-.265
	Sig. (2-tailed)	.003	.	.001	.156	.563	.443	.199	.269	.277	.628	.050	.255	.231	.283	.044
	N	67	69	64	59	59	59	59	59	59	58	58	59	59	58	58
FMCE posttest score	Pearson Correlation	.673	.421	1.000	.000	.004	.054	-.209	.010	-.111	-.066	.091	-.094	-.073	.014	-.050
	Sig. (2-tailed)	.000	.001	.	.997	.978	.693	.122	.943	.415	.630	.507	.492	.591	.918	.718
	N	63	64	65	56	56	56	56	56	56	55	55	56	56	55	55
Perceived IT skill (final)	Pearson Correlation	.059	.187	.000	1.000	.166	.179	-.245	.027	.099	.075	.020	.307	-.196	-.122	-.103
	Sig. (2-tailed)	.662	.156	.997	.	.204	.171	.059	.835	.450	.594	.888	.025	.160	.388	.466
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
IT confidence (final)	Pearson Correlation	.099	.077	.004	.166	1.000	.068	-.332	.021	.039	-.132	.085	.039	.154	.174	.247
	Sig. (2-tailed)	.461	.563	.978	.204	.	.606	.009	.876	.765	.346	.551	.781	.271	.217	.077
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
FAQLPOST	Pearson Correlation	-.115	.102	.054	.179	.068	1.000	.120	.203	-.047	-.394	-.232	-.040	-.080	-.070	-.067
	Sig. (2-tailed)	.389	.443	.693	.171	.606	.	.362	.120	.724	.004	.097	.774	.571	.624	.639
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
SKPOST	Pearson Correlation	-.140	-.170	-.209	-.245	-.332	.120	1.000	.228	-.248	-.161	-.341	.080	-.179	-.083	-.225
	Sig. (2-tailed)	.293	.199	.122	.059	.009	.362	.	.080	.056	.250	.013	.567	.200	.558	.108
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
CKPOST	Pearson Correlation	-.290	-.146	.010	.027	.021	.203	.228	1.000	.087	.037	-.235	.143	-.081	.038	-.221
	Sig. (2-tailed)	.027	.269	.943	.835	.876	.120	.080	.	.509	.792	.093	.309	.566	.790	.115
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
EAPOST	Pearson Correlation	-.192	-.144	-.111	.099	.039	-.047	-.248	.087	1.000	.093	-.165	.024	-.167	-.005	-.073
	Sig. (2-tailed)	.148	.277	.415	.450	.765	.724	.056	.509	.	.509	.241	.862	.231	.974	.607
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	52	52
Relevance (actual)	Pearson Correlation	-.023	.065	-.066	.075	-.132	-.394	-.161	.037	.093	1.000	.255	.251	.349	.381	.355
	Sig. (2-tailed)	.863	.628	.630	.594	.346	.004	.250	.792	.509	.	.053	.055	.007	.003	.006
	N	57	58	55	53	53	53	53	53	53	59	58	59	59	58	58
Reflection (actual)	Pearson Correlation	.164	.259	.091	.020	.085	-.232	-.341	-.235	-.165	.255	1.000	.040	.261	.116	.284
	Sig. (2-tailed)	.224	.050	.507	.888	.551	.097	.013	.093	.241	.053	.	.766	.046	.386	.031
	N	57	58	55	52	52	52	52	52	52	58	59	59	59	58	58
Negotiation (actual)	Pearson Correlation	-.058	-.151	-.094	.307	.039	-.040	.080	.143	.024	.251	.040	1.000	.063	.230	.038
	Sig. (2-tailed)	.663	.255	.492	.025	.781	.774	.567	.309	.862	.055	.766	.	.633	.079	.773
	N	58	59	56	53	53	53	53	53	53	59	59	60	60	59	59
Leadership (actual)	Pearson Correlation	-.138	-.158	-.073	-.196	.154	-.080	-.179	-.081	-.167	.349	.261	.063	1.000	.549	.741
	Sig. (2-tailed)	.301	.231	.591	.160	.271	.571	.200	.566	.231	.007	.046	.633	.	.000	.000
	N	58	59	56	53	53	53	53	53	53	59	59	60	60	59	59
Empathy (actual)	Pearson Correlation	-.019	-.143	.014	-.122	.174	-.070	-.083	.038	-.005	.381	.116	.230	.549	1.000	.586
	Sig. (2-tailed)	.891	.283	.918	.388	.217	.624	.558	.790	.974	.003	.386	.079	.000	.	.000
	N	57	58	55	52	52	52	52	52	52	58	58	59	59	59	58
Support (actual)	Pearson Correlation	-.007	-.265	-.050	-.103	.247	-.067	-.225	-.221	-.073	.355	.284	.038	.741	.586	1.000
	Sig. (2-tailed)	.957	.044	.718	.466	.077	.639	.108	.115	.607	.006	.031	.773	.000	.000	.
	N	57	58	55	52	52	52	52	52	52	58	58	59	59	58	59

Table A.7. Correlations among SI students' final EBs, COs, IT measures and Preferred LE attitudes

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST	Relevance (preferred)	Reflection (preferred)	Negotiation (preferred)	Leadership (preferred)	Empathy (preferred)	Support (preferred)
Semester 1 exam score	Pearson Correlation	1.000	.622	.521	-.033	.139	-.057	-.327	.050	-.154	-.062	-.209	-.095	-.459	-.226	-.264
	Sig. (2-tailed)	.	.000	.000	.831	.367	.712	.028	.745	.314	.711	.208	.570	.004	.178	.114
	N	45	43	42	44	44	45	45	45	45	38	38	38	37	37	37
Quantum Mechanics test score	Pearson Correlation	.622	1.000	.465	.006	.120	-.087	-.385	.048	-.278	.116	-.265	.109	-.468	-.076	-.132
	Sig. (2-tailed)	.000	.	.002	.970	.450	.581	.011	.762	.072	.500	.118	.525	.005	.664	.449
	N	43	43	42	42	42	43	43	43	43	36	36	36	35	35	35
FMCE posttest score	Pearson Correlation	.521	.465	1.000	.231	.116	.013	-.275	.074	-.267	-.121	.008	-.007	-.210	-.287	-.153
	Sig. (2-tailed)	.000	.002	.	.147	.470	.933	.078	.639	.087	.488	.966	.970	.234	.100	.389
	N	42	42	42	41	41	42	42	42	42	35	35	35	34	34	34
Perceived IT skill (final)	Pearson Correlation	-.033	.006	.231	1.000	.235	-.100	-.090	.017	.204	.289	.219	.366	.181	.108	-.037
	Sig. (2-tailed)	.831	.970	.147	.	.124	.518	.560	.913	.184	.083	.192	.026	.292	.532	.832
	N	44	42	41	44	44	44	44	44	44	37	37	37	36	36	36
IT confidence (final)	Pearson Correlation	.139	.120	.116	.235	1.000	.156	.181	.037	.038	-.086	-.094	-.004	-.152	-.148	-.181
	Sig. (2-tailed)	.367	.450	.470	.124	.	.310	.239	.813	.804	.613	.582	.979	.376	.390	.291
	N	44	42	41	44	44	44	44	44	44	37	37	37	36	36	36
FAQLPOST	Pearson Correlation	-.057	-.087	.013	-.100	.156	1.000	.209	.112	-.351	-.144	-.268	-.337	-.299	-.323	-.198
	Sig. (2-tailed)	.712	.581	.933	.518	.310	.	.168	.466	.018	.389	.103	.038	.072	.051	.240
	N	45	43	42	44	44	45	45	45	45	38	38	38	37	37	37
SKPOST	Pearson Correlation	-.327	-.385	-.275	-.090	.181	.209	1.000	-.070	.028	-.332	-.067	.040	-.147	-.097	-.100
	Sig. (2-tailed)	.028	.011	.078	.560	.239	.168	.	.646	.858	.042	.689	.812	.387	.568	.555
	N	45	43	42	44	44	45	45	45	45	38	38	38	37	37	37
CKPOST	Pearson Correlation	.050	.048	.074	.017	.037	.112	-.070	1.000	-.072	-.077	.178	-.246	.075	.203	.070
	Sig. (2-tailed)	.745	.762	.639	.913	.813	.466	.646	.	.638	.646	.286	.136	.659	.229	.682
	N	45	43	42	44	44	45	45	45	45	38	38	38	37	37	37
EAPOST	Pearson Correlation	-.154	-.278	-.267	.204	.038	-.351	.028	-.072	1.000	.034	-.008	.207	.381	.285	.041
	Sig. (2-tailed)	.314	.072	.087	.184	.804	.018	.858	.638	.	.840	.963	.212	.020	.087	.811
	N	45	43	42	44	44	45	45	45	45	38	38	38	37	37	37
Relevance (preferred)	Pearson Correlation	-.062	.116	-.121	.289	-.086	-.144	-.332	-.077	.034	1.000	.036	.305	.478	.157	.406
	Sig. (2-tailed)	.711	.500	.488	.083	.613	.389	.042	.646	.840	.	.830	.062	.003	.355	.013
	N	38	36	35	37	37	38	38	38	38	38	38	38	37	37	37
Reflection (preferred)	Pearson Correlation	-.209	-.265	.008	.219	-.094	-.268	-.067	.178	-.008	.036	1.000	.177	.470	.367	.322
	Sig. (2-tailed)	.208	.118	.966	.192	.582	.103	.689	.286	.963	.830	.	.288	.003	.025	.052
	N	38	36	35	37	37	38	38	38	38	38	38	38	37	37	37
Negotiation (preferred)	Pearson Correlation	-.095	.109	-.007	.366	-.004	-.337	.040	-.246	.207	.305	.177	1.000	.198	.354	.087
	Sig. (2-tailed)	.570	.525	.970	.026	.979	.038	.812	.136	.212	.062	.288	.	.240	.032	.607
	N	38	36	35	37	37	38	38	38	38	38	38	38	37	37	37
Leadership (preferred)	Pearson Correlation	-.459	-.468	-.210	.181	-.152	-.299	-.147	.075	.381	.478	.470	.198	1.000	.378	.555
	Sig. (2-tailed)	.004	.005	.234	.292	.376	.072	.387	.659	.020	.003	.003	.240	.	.021	.000
	N	37	35	34	36	36	37	37	37	37	37	37	37	37	37	37
Empathy (preferred)	Pearson Correlation	-.226	-.076	-.287	.108	-.148	-.323	-.097	.203	.285	.157	.367	.354	.378	1.000	.594
	Sig. (2-tailed)	.178	.664	.100	.532	.390	.051	.568	.229	.087	.355	.025	.032	.021	.	.000
	N	37	35	34	36	36	37	37	37	37	37	37	37	37	37	37
Support (preferred)	Pearson Correlation	-.264	-.132	-.153	-.037	-.181	-.198	-.100	.070	.041	.406	.322	.087	.555	.594	1.000
	Sig. (2-tailed)	.114	.449	.389	.832	.291	.240	.555	.682	.811	.013	.052	.607	.000	.000	.
	N	37	35	34	36	36	37	37	37	37	37	37	37	37	37	37

Table A.8. Correlations among TI students' final EBs, COs, IT measures and Preferred LE attitudes

		Semester 1 exam score	Quantum Mechanics test score	FMCE posttest score	Perceived IT skill (final)	IT confidence (final)	FAQLPOST	SKPOST	CKPOST	EAPOST	Relevance (preferred)	Reflection (preferred)	Negotiation (preferred)	Leadership (preferred)	Empathy (preferred)	Support (preferred)
Semester 1 exam score	Pearson Correlation	1.000	.362	.673	.059	.099	-.115	-.140	-.290	-.192	-.147	-.031	-.318	-.100	-.190	-.298
	Sig. (2-tailed)	.	.003	.000	.662	.461	.389	.293	.027	.148	.270	.819	.015	.457	.154	.025
	N	68	67	63	58	58	58	58	58	58	58	57	58	58	58	57
Quantum Mechanics test score	Pearson Correlation	.362	1.000	.421	.187	.077	.102	-.170	-.146	-.144	-.066	.122	-.202	-.244	-.137	-.287
	Sig. (2-tailed)	.003	.	.001	.156	.563	.443	.199	.269	.277	.619	.362	.124	.063	.302	.029
	N	67	69	64	59	59	59	59	59	59	59	58	59	59	59	58
FMCE posttest score	Pearson Correlation	.673	.421	1.000	.000	.004	.054	-.209	.010	-.111	-.091	.029	-.232	.008	-.048	-.160
	Sig. (2-tailed)	.000	.001	.	.997	.978	.693	.122	.943	.415	.506	.835	.085	.952	.725	.244
	N	63	64	65	56	56	56	56	56	56	56	55	56	56	56	55
Perceived IT skill (final)	Pearson Correlation	.059	.187	.000	1.000	.166	.179	-.245	.027	.099	.058	-.103	.100	-.219	-.155	-.046
	Sig. (2-tailed)	.662	.156	.997	.	.204	.171	.059	.835	.450	.681	.465	.475	.116	.267	.745
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
IT confidence (final)	Pearson Correlation	.099	.077	.004	.166	1.000	.068	-.332	.021	.039	.080	-.272	-.209	-.207	-.148	-.188
	Sig. (2-tailed)	.461	.563	.978	.204	.	.606	.009	.876	.765	.570	.051	.133	.137	.292	.182
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
FAQLPOST	Pearson Correlation	-.115	.102	.054	.179	.068	1.000	.120	.203	-.047	-.152	-.294	-.236	-.362	-.252	-.253
	Sig. (2-tailed)	.389	.443	.693	.171	.606	.	.362	.120	.724	.278	.035	.089	.008	.068	.070
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
SKPOST	Pearson Correlation	-.140	-.170	-.209	-.245	-.332	.120	1.000	.228	-.248	.110	-.041	.147	.119	.384	.228
	Sig. (2-tailed)	.293	.199	.122	.059	.009	.362	.	.080	.056	.434	.771	.295	.397	.005	.103
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
CKPOST	Pearson Correlation	-.290	-.146	.010	.027	.021	.203	.228	1.000	.087	-.034	-.002	.126	.090	.073	.065
	Sig. (2-tailed)	.027	.269	.943	.835	.876	.120	.080	.	.509	.808	.986	.367	.520	.603	.645
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
EAPOST	Pearson Correlation	-.192	-.144	-.111	.099	.039	-.047	-.248	.087	1.000	-.196	-.062	.162	-.127	-.028	-.142
	Sig. (2-tailed)	.148	.277	.415	.450	.765	.724	.056	.509	.	.160	.662	.246	.365	.842	.315
	N	58	59	56	60	60	60	60	60	60	53	52	53	53	53	52
Relevance (preferred)	Pearson Correlation	-.147	-.066	-.091	.058	.080	-.152	.110	-.034	-.196	1.000	.209	.183	.352	.480	.611
	Sig. (2-tailed)	.270	.619	.506	.681	.570	.278	.434	.808	.160	.	.112	.162	.006	.000	.000
	N	58	59	56	53	53	53	53	53	53	60	59	60	60	60	59
Reflection (preferred)	Pearson Correlation	-.031	.122	.029	-.103	-.272	-.294	-.041	-.002	-.062	.209	1.000	.411	.521	.409	.460
	Sig. (2-tailed)	.819	.362	.835	.465	.051	.035	.771	.986	.662	.112	.	.001	.000	.001	.000
	N	57	58	55	52	52	52	52	52	52	59	59	59	59	59	58
Negotiation (preferred)	Pearson Correlation	-.318	-.202	-.232	.100	-.209	-.236	.147	.126	.162	.183	.411	1.000	.269	.538	.523
	Sig. (2-tailed)	.015	.124	.085	.475	.133	.089	.295	.367	.246	.162	.001	.	.038	.000	.000
	N	58	59	56	53	53	53	53	53	53	60	59	60	60	60	59
Leadership (preferred)	Pearson Correlation	-.100	-.244	.008	-.219	-.207	-.362	.119	.090	-.127	.352	.521	.269	1.000	.534	.693
	Sig. (2-tailed)	.457	.063	.952	.116	.137	.008	.397	.520	.365	.006	.000	.038	.	.000	.000
	N	58	59	56	53	53	53	53	53	53	60	59	60	60	60	59
Empathy (preferred)	Pearson Correlation	-.190	-.137	-.048	-.155	-.148	-.252	.384	.073	-.028	.480	.409	.538	.534	1.000	.774
	Sig. (2-tailed)	.154	.302	.725	.267	.292	.068	.005	.603	.842	.000	.001	.000	.000	.	.000
	N	58	59	56	53	53	53	53	53	53	60	59	60	60	60	59
Support (preferred)	Pearson Correlation	-.298	-.287	-.160	-.046	-.188	-.253	.228	.065	-.142	.611	.460	.523	.693	.774	1.000
	Sig. (2-tailed)	.025	.029	.244	.745	.182	.070	.103	.645	.315	.000	.000	.000	.000	.000	.
	N	57	58	55	52	52	52	52	52	52	59	58	59	59	59	59

APPENDIX A3

Papers

Note: For copyright reasons Appendix A3, which contains the following articles, has not been reproduced.

Yeo, S. & Zadnik, M. (2001) Introducing thermal concept evaluation: Assessing students understanding. *The Physics Teacher.* 39 (Nov): 496-504.

Yeo, S., The interrelationships of students' epistemological beliefs, learning preferences and cognitive outcomes in two first year university physics classes [Unpublished]

(Co-ordinator, ADT Project, Curtin University of Technology, 3.8.04)