The use of a virtual environment in the education of engineering students

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THE USE OF A VIRTUAL ENVIRONMENT IN THE EDUCATION OF ENGINEERING STUDENTS

by

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ABSTRACT

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This study explores the educational value of using three-dimension (3D) interactive technology in a virtual reality (VR) environment to augment the learning of engineering students at the polytechnic level in Temasek Polytechnic, Singapore. The virtual environment (VE) consists of a factory floor with different planning tools and machines which students need to interact with to achieve an optimum production rate. Forty second-year engineering students opting for the Computer Integrated Manufacturing (CIM) third year elective were used as subjects. They were separated into two groups of twenty students. The second-year examination results from these two groups of students showed that there was no statistical difference between them, implying that both groups of students had similar initial knowledge. The VR augmentation group used a combined lecture/tutorial format to cover theories of the subject and used the VE as a learning tool to further improve their understanding by solving problems. The traditional instruction group used course notes, tutorial work sheets and teacher-led discussions. The instruments used include a post-test to measure performance, a survey questionnaire consisting of thirty-three 4-point Likert Scale questions, three essay questions, one ranking question and a final concept map type of question. This was followed by an interview to provide a deeper understanding of the use of VR in augmenting the learning process by probing for further details. Results in the post-test indicated that there was no significant difference in the score obtained by students undergoing VR augmentation and the traditional group ($p=0.167$, $d=0.44$). However, it was noted that the mean for every question was consistently higher for the VR augmented group. A more detailed analysis showed that for questions relating to problem solving, there was statistical significance ($p=0.038$, $d=0.68$) between the scores from the VR augmented group scores and the traditional group. Analysis of inputs from the survey questionnaire and the interview led to a further understanding of the learning aspects of VR, namely the features, learner characteristics, interactive experience, learning experience and the learning itself. This consequently led to an enhanced model of learning in VR.

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DECLARATIONS

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material, previously published or written by another person except where due reference is made in the thesis itself.

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GLOSSARY

3D. See Three Dimensional.

Affordances. Distinguishing features of a thing that identifies it. Theory of affordance refers to awareness of an individual in an environment and his interactions with the environment.

Behaviour. Actions ascribed to virtual objects in a virtual environment.

Catharsis. To get off one's chest. To find whatever works in order to find peace with oneself.

Computer Graphics (CG). Display of non-verbal information that is conveyed spatially.

Computer Simulation. A computer model of a real phenomenon or system. A 3D simulation is described by 3D models in a computer program. Simulations are used in computer games, training programs (flight simulators) and by scientists, who recreate, project into the future and predict real world phenomena.

Computer Visuals. Refer to all possible computer output, including text.

Concept Mapping. A process where individuals organize a domain of knowledge for themselves and express their understanding of the various inter-relationships in the form of a diagram.

Geometry. The description of an object in terms of its dimensions.

Head Mounted Display (HMD). A set of goggles or a helmet with tiny monitors in front of each eye that generate images seen by the wearer as being 3-D.

Immersion; Immersive. The user feels as if he or she is placed within the environment. This feeling is often referred to as presence.

Interactions. Interactions are those behaviours that occur between participant and environments, participant and object, or object to object. They are often cause-and-effect driven, thought they can certainly be programmed to be much more arbitrary. Interactions are what make virtual environments interesting.

Mental Models. Mental models are the conceptual representations that humans (and perhaps other organisms create to give meaning to their experiences and knowledge. Mental models can be likened to large hierarchical and relational networks, whereby information is taken from the environment, and meaning is constructed in a manner that makes sense to the individual.

Presence. One of the defining characteristics of a good VR system, a feeling of being there.

Real-time. A phrase used to describe computer graphics and interactions that appear to the user without lag or flicker . Real-time graphics and interactions contribute to the participant's sense of presence, in that the brain is not forced to wait for feedback from the system once an action or interaction has been initiated.

Simulation sickness. The disturbances produced by simulators, ranging in degree from a feeling of unpleasantness, disorientation, and headaches to nausea and vomiting. Many factors may be involved, including sensory distortions such as abnormal movement of arms and heads because of the weight of equipment; long delays or lags in feedbacks, and missing visual cues from convergence and accommodation.

Syllogistic reasoning. A form of reasoning in which two given or assumed prepositions leads to a conclusion.

Tactile Cues, Tactile Feedback. Sensation applied to the skin, typically in response to contact or other actions in a virtual environment.

Three Dimensional (3D). A term referring to the three planes used to describe an object that occupies space, i.e. length, breadth and height.

Virtual Environments (VE). The sense of place and being which exists in cyberspace. An Immersive, interactive simulation of realistic or imaginary environments. Realistic simulations of interactive scenes. See Virtual Reality

Virtual Reality (VR). The technology that provides realistic interactive and immersive simulation in three dimension.

Visualisation. Use of computer graphics to make visible numeric or other quantifiable relationships.

Visual Literacy. The ability to understand and use images and to think and learn in terms of images.

PART I

INTRODUCTION

1. OVERVIEW

1.1 Background

In developed countries, sophisticated computers and telecommunications are on the verge of reshaping the mission, objectives, content, and processes of schooling (Dede 2000). This is part of a larger change in those nations from loosely-coupled, mature industrial economies to a profoundly interconnected, knowledge-based global market (Dertouzos & Gates 1998). Driven by advances in information technology, this economic evolution is a huge leap from the workplace of yesterday to that of tomorrow's since the last two centuries (Thurow 1999). In response, all forms of societal institutions are altering slowly, but radically, including educational institutions. Since one of education's goals is to prepare students for work and citizenship, schools are attempting to change their policies, practices and curriculum to meet the challenge of making students ready for a future quite different from the immediate past. (Tucker & Codding 1998).

According to Hanna (2000), approaches to and theories of learning and teaching have evolved in concert with the development of technologies and demands from the work environment for different knowledge and skill sets from those previously required by a highly structured, compartmentalised, and ordered industrial economy. Knowledge that people need to live and work in today's society is increasingly interdisciplinary, problem-focused, and process based rather than linear, routine and well defined. Similarly, Gardiner (1994) reiterates that proficiencies required of workers today include the ability to work in teams, have excellent presentation skills, critical thinking processes and the capacity to use a variety of technologies and software. Gardiner felt that students would need to develop an internal process for learning that will enable them to be continuous learners. Mecklenburger (1993), in his work on re-building the next generation of American schools commented that the characteristics of an "educated person" in society today are as follows:

"Because now we live in an information age and electronic networks are linking the world into a global village, an educated person is one who has the ability to find what is known, then to think about what is known, to reflect upon changes in what is known, to explore, to share, to debate, to question, to compare and contrast, to solve problems, to engage in what today's educators call 'higher order thinking skills' and to contribute to what is known." (pp. 42)

Similarly, in Singapore, in a speech on 'Opening New Frontiers in Education with Information Technology', at the launch of Singapore's Masterplan for IT, Rear Admiral Teo Chee Hean, the then Minister for Education and Second Minister for Defence noted that:

"Singaporeans must learn to think beyond the obvious, to think creatively, to search for new knowledge, to come up with new ideas. They must be comfortable with new technologies and be able to exploit these new technologies to venture beyond their current boundaries and open up new frontiers of knowledge". (Teo C.H. (Rear Admiral) 1997)

From the above literature, it would seem that the use of technology has permeated almost all levels of society and will become important in the pursuit of meaningful learning. However, the use of technology in education has always been problematic. Richard Clark (1983) has for many years argued that technologies are "mere vehicles" that deliver instructional messages to learners. When technology was used to deliver instructional messages, students generally learn no differently from technologies or teachers. Oppenheimer (1997) in a cover story of the *Atlantic Monthly* illustrates another critical view of technology in education in that "There is no good evidence that most uses of computers significantly improve teaching and learning". The controversy in the popular press is echoed in the educational research literature. Research examining the effectiveness of media and technology in schools can be traced back almost eighty years (Cuban 1986) and yet many questions about the value and impact of these approaches remain unanswered. Indeed, the seemingly contradictory findings often reported in the educational literature fan the flames of the ongoing controversy about technology in education.

In delving into a research area concerning media and technology in education, perhaps a good starting point would be to look at Kozma's (1994) advice. He recommended that instead of concentrating on questions about whether technology impacts learning, researchers should be looking at questions concerning the ways in which the capabilities of technology and media influence learning for particular students with specific tasks in distinct contexts.

According to Bonwell & Eison (1991) and Gardiner (1994), models that aid the development of active, engaged learners, need to be created to support the students in the new learning environment. The ideal would be an activity that intrinsically "engages" the learner, and leads them through an interactive experience that enhances their ability to "think". The concept of engaged learning builds upon the work of diverse thinkers such as Dewey (1916) and Vygotsky (1962), both of whom argued strongly that learning occurs most effectively when it is connected to the personal experience and knowledge base of the learner, and when it is situated in a social context in which the learner leads the "construction" of his or her own knowledge through interactions. Hence in an engaged-learner classroom, the learner becomes the primary interpreter or integrator of knowledge and information with the teacher's role becoming one of coaching, guiding and mediating among possible classroom activities and pursuits within the framework of overall course content. Thus, learning must necessarily actively involve and engage the learner, beginning with the knowledge that the learner carries into the classroom environment. According to Winn (1997), understanding arises as the learners work to reconcile what they already know and believe with information they are encountering for the first time or with old information on which they are gaining a fresh perspective. It is this struggle to construct knowledge within an existing framework – that results in learner enthusiasm, involvement and engagement.

Jones et. al. (1994) outline indicators of environments that induce and support engaged learners and provide examples of student abilities that are supported in such an environment. According to them, engaged learners are actively responsible for defining their own goals:

> *"Successful engaged learners are responsible for their own learning. These students are self-regulated and able to define their own learning goals and evaluate their own achievement. They are also energised by their learning; their joy of learning leads to a life-long passion for solving problems, understanding, and taking the next step in their thinking. These learners are strategic in that they know how to learn*

and are able to transfer knowledge to solve problems creatively. Engaged learning also involves being collaborative, that is, valuing and having the skills to work with others."

In order for engagement to occur in a learning experience, Quinn (1997) maintained that three essentials must be present. They are, learning, interaction and "flow and fun". *Learning* approaches need to include elements such as motivating the learning by demonstrating the practical applications and importance of the knowledge, providing a conceptual description of the skill, demonstrating the application of the knowledge to practical problems, providing practice opportunities with support in the form of scaffolding, and facilitating transfer through guided reflection on the activity to integrate the practical issues with the underlying conception. Quinn's justification for these elements is spread across approaches such as problem-based learning (Barrows 1986), cognitive apprenticeship (Collins, Brown & Newman 1989), Laurillard's (1993) pragmatic approach and others. He noted the increasing emphasis on exploration and discovery, where the learner takes responsibility for constructing their own knowledge. Activities that reflect the application of the content knowledge as it is practised outside the classroom is encouraged, with the goal being to induct the learner into a "culture of practice" which makes the knowledge meaningful. Another implication is that the feedback ideally should be intrinsically embedded into the context in which the activity is performed within a carefully managed level of challenge.

Approaches to making computer-based tasks "direct" also form part of the *interaction* process. Innovations in interface design (interestingly, many were first seen commercially in games) were providing a new experience of using a computer, and several researchers have tried to summarise the elements that contributed to the feeling of directly manipulating the computer environment. Shneiderman (1983) and Hutchins, Hollan & Norman (1986) suggested that the tight coupling between the action and feedback was important, both in the form of the communication, and in the time between action and response. In addition, complex syntax is replaced by direct manipulation on representations that are familiar from other experience. This concept of direct interaction is certainly not new but an adapted form of "learning by doing" (Bruner 1990).

Another element is the broad investigation of the affective experience of *fun*. Explorations have included the experience of the "*flow*" state (Czikzentmihalyi & Czikzentmihalyi 1988) and considerations of what makes computer games "*fun*" (Malone 1981). Malone indicated three factors: fantasy, the scenario in which the activity is embedded; challenge, the level of difficulty; and curiosity, the introduction of new information and non-deterministic outcomes. Czikzentmihalyi expands the concept of challenge, indicating that the level of challenge needs to be matched to skills, and should be greater than average. Another important element is having clear goals for the activity. Finally, the flow state is highest when the individual is the locus of control.

It was noted that many elements are repeated in the different areas. Feedback is highlighted in several, as are goals and control, challenge, thematic coherence and the need for direct action. There appears to be a close association between play and learning. Computer games enhance learning through visualisation, experimentation and creativity of play (Betz 1995) and often include problems that develop critical thinking which is defined by Huntington (1984) as the analysis and evaluation of information in order to determine logical steps that lead to concrete conclusions. Visualisation, a key cognitive strategy, plays an important role in discovery and problem solving (Rieber 1995). Visualisation, therefore, has tremendous value in the process of learning. Mandl & Levin (1989) and Willows & Houghton (1987) in their separate researches showed that the extensive use of visualisation symbols systems such as still and animated pictures, simplified visual analogs, schematics, pictorial metaphors and simulations can contribute to learning. Also, many problems, in real life and in computer games require the manipulation of objects, or elements in these exploratory environments and can be involved in goal formation and competition. Leutner (1993) argued that manipulation of objects simulates learning and training while Neal (1990) proposed that goal formation and competition are inherently motivating components in engaging learning.

1.2 Research Questions

The use of technology to enhance "engagement" in learning provides a backdrop for introducing the topic of using a highly interactive visual learning environment known as virtual reality (VR). Visualisation, as shown in section 1.1, is a valuable means to promote learning. Virtual reality, defined by Lawrence & Pantelidis (1999) as "a computer-generated simulation of a real or an imagined environment or world" is a "meta-medium" that allows different forms of visualisation to take place. It represents a break with the long line of technological "information providers" or media that have appeared over the years, such as radio, television, video, computers and multimedia. The break occurs because of the ability of the participant to interact in real time with a multi-perceptual, multi-dimensional, inclusive, potentially multi-participant environment; to change perspective at will, to make and implement decisions, to experience a "paradigm shift" in a wholly created system that exists in the computer and the minds of the world designers and participants. Osberg (1993) suggested that perhaps the most important potential aspect of VR is the possibility of creating new symbol systems, which can be used to better understand concepts and relations. In allowing learning "with" technology instead of learning "from" technology, Jonassen & Reeves (1996) suggested that VR is able to engage the students in developing higher-level thinking skills essential to synthesizing knowledge.

Although this evolution of "meta-medium" environment will enable artificial realities that immerse students in information-laden virtual worlds, Dede (1992) cautioned that they risk overwhelming their users and both teachers and students have to master the cognitive skills essential to constructing meaningful knowledge in their learning, suggesting that there is a need to study how these new mediums will impact and influence learning.

In seeking to provide an educational environment in which students take an active role in their learning process, could the three-dimension (3D) interactive technology used in a VR environment (also known as a virtual environment or VE), provide a learning opportunity that is both engaging and stimulating for students? By accessing information in a variety of media formats and in an interactive fashion, could students make useful associating through their own explorations? In using a VE, could students attribute meaning to objects, relationships and behaviours in a way that mirrors their personal understanding, thus extending their understanding in the specified domain area?

Hence, this dissertation is an exploration into the use of a VR learning environment in a specific context as suggested by Kozma (1994). This research was intended as a study to explore whether the use of a VR learning environment was able to improve student learning as well as its impact on student learning. Research questions identified were:

1. Did VR technology help improve students' learning processes when compared to traditional classroom methods? How did it help?

2. Which aspects of using VR assisted the learning process?

3. Were students motivated by the VR experience?

4. Which aspects of using VR motivated the students?

5. Were students still able to collaborate while learning through a VR environment?

6. Did students prefer VR as a learning tool to traditional methods?

The context in which these questions were asked was in the area of engineering in a tertiary-level technical college in Singapore. In engineering, the use of simulation has always been accepted as a means to solve complex problems or problems that are difficult to describe (Harding 1998). So logically, VR would hold much promise for education and training in this field (Tan 2000). Current research in using VR for education seemed to target children's (Bricken & Byrne 1992, Osberg et. al. 1997, Lawrence & Pantelidis 1999, Roussos et. al. 1999 and Winn et. al. 1999) education and very little work has been done in the domain of tertiary education. This study also focuses on Desktop VR systems rather than immersive VR system compared to the examples listed above. Desktop VR applications on personal computers allow users to walk through simulated environments. Some slightly more expensive systems add peripheral devices to provide a higher degree of interactivity. These systems lack immersive qualities. Immersive VR systems use high-end equipment, hence are consequently limited to situations with special funding, such as academic and research environments.

1.3 Structure of Thesis

The thesis is divided into 7 chapters. Chapter one introduces the background of the research, leading to the research area and finally identification of the research questions. Chapter two reviews and critiques literature in the area of using VR in education, to provide an in-depth understanding of issues in the research area. Chapter 3 follows through from chapter 2 to delve further into the underpinning of learning in VR by reviewing the models of learning. Chapter 4 describes the research methodology, the design, the procedures and the instruments used. Chapters 5 and 6 report the findings of the experiment and Chapter 7 provides the concluding discussion.

PART II

LITERATURE REVIEW

2. LEARNING IN VIRTUAL ENVIRONMENTS

The meanings of the terms visual, graphic, image and picture greatly overlap and are often used synonymously. Strictly speaking, computer visuals refer to all possible computer output, including text. Instructional computer graphics are considered a subset of computer visuals and involves the display of *nonverbal information*, or information that is conveyed spatially. Included in this definition are the ranges of computer-generated pictures, with pictures being defined as graphics that share some physical resemblance to an actual person, place or thing. The quality of these types of graphics ranges from near-photographic to crude line drawings. Also included is the spectrum of non-representational graphics, including, but not limited to, charts, diagrams and schematics (Rieber 1994).

The term visualisation, besides its general meaning is used to describe the interdisciplinary field of study in which computer graphics techniques are used to display images that convey a wide range of information. In this sense, visualisation differs from computer graphics in that visualisation stresses the information that is conveyed in the resulting image (Brown & Cunningham 1990).

The framework for using virtual reality (VR) in education is tied closely to how graphics and visualisation was developed in this area. In this chapter, the history of visualisation is covered first to set the stage for an introduction into using VR in learning environments. This is followed by critiques and discussions of the work of several prominent authors in the area of learning in VR. The findings will be used to stage Chapter 3, where learning models will be discussed in relation to learning in virtual environments and Chapter 4, where research findings and questions raised in this chapter are incorporated into the design of experiment.

2.1 History of Graphics & Visualisation in Education

2.1.1 Static Visuals

Instructionally, the role of graphics in computer environments covers a lot of ground. The computer can be used for traditional applications, such as graphics that present static informational images or text that helps someone to understand a concept or principle. Much of the instructional visual research over the past forty years has pertained to applications such as these. Although most of this research has been in non-computer contexts, it is still quite relevant (Rieber 1994). The use of graphics in education has a long history. The use of illustrations in books written in English, especially those intended for children, was commonplace by about 1840 (Slythe 1970). After that time, the use of illustration in children's books has been especially extensive, elaborate, and artistic (Feaver 1977). A wide variety of graphics – from photographs, pictures, and cartoons, to charts, maps, diagrams and outlines – is common today in most teaching strategies. The use of graphics in instruction seemed to make sense – it holds a certain degree of face validity. The cliché that a picture is worth a thousand words seems consistent with educational practice. However, research has shown that the relationship between the intent and results of graphics in education is often jumbled (Samuels 1970).

Given the widespread use of illustrations and other types of graphics in instruction, one would think that there would be definitive research literature to either support or dispel their usefulness. Although the use of pictures as an instructional aid has been a very popular research issue, the literature is far from definitive and, at first glance, can even appear contradictory. For example, researchers studying the effects of pictures in prose learning prior to 1970 concluded that pictures often did not aid children's learning and were even distracting at times (Braun 1969, Samuels 1967, 1970). In almost all of the studies Samuels reviewed on the use of pictures in teaching simple vocabulary to children, there was usually either no difference between the picture and no-picture groups, or students performed better with no accompanying pictures. His studies in the area of comprehension and attitudes, unfortunately, posed many problems, making interpretation ambiguous at best. First, too few studies were represented in each case – for example, only two were involved in the case of attitudes. Second, the studies that were represented appeared prone to confounding variables, for example, many of the comprehension studies tested for memory, not comprehension. The quality of the design of the studies is also easily questioned. The value of Samuels' review relates to its evidence of the potential distracting nature of visuals. Samuels concluded that students, usually those with below-average reading skills, had difficulty shifting their attention from a picture to a written word because the picture required less effort. Research conducted since 1970 has been more supportive, not because students were somehow different now, but because there is a better sense of understanding of the conditions under which visuals work. This implies that not only do a set of "conditions" exist, but that pictures will not, and should not, help learning in every instance. Findings by Pressley (1977) suggested that pictures can exert strong positive influences on learning, given certain conditions, for example, that children's dependence on pictures decreases with age, they become better able to produce their own internal images. Studies by Guttmann et. al. (1977), Shimron 1975, Lesgold et. al. (1975) also seemed to suggest that the developmental importance of imagery ability and skills like other cognitive processes, probably develop over time. Other research, although supporting the claim that children depend less on outside images, as they grow older, demonstrated that pictures could decrease the difficulty of prose material for older children. Levin and Divine-Hawkins (1974) demonstrated that fourth-grade children do not automatically construct images, although they are capable of doing so. This finding led to many examples of successful training of subjects to form mental images (Lesgold, McCormick & Golinkoff, 1975, Pressley 1976). Dwyer's (1972, 1978, 1987) extensive research findings act as a testimonial to all of instructional visual research because they show repeatedly that visuals are not equally effective across learning situations. Effectiveness of all instructional strategies, such as visuals, depends on a wide array of factors, such as the picture being relevant to the information presented in the test, pictures designed to perform their appropriate instructional functions based on the needs of the learner and so on. The most consistent results found by Dwyer were related to the amount of realism in the visuals. His results suggested that people need sufficient time to scan and interpret visuals with highly realistic details. Levie (1987) provided the broadest views of picture research, reviewing the four areas of: picture perception, memory for pictures, learning and cognition, and affective responses to pictures. In reviewing the four areas, Levie suggested that "an aerial view of the picture research literature would look like a group of small tropical islands with only a few connecting bridges in between" (Levie 1987, p. 26). Research on recognition memory for pictures constitutes the largest pool on a single topic. Levie noted that very little research is available on the role of pictures in higher-order thinking, such as problem solving. However, he concluded that there was some evidence to suggest that visual thinking plays an important part in skills associated with syllogistic reasoning. Relative to the cognitive domain, Levie also commented that there was very little research available on the affective effects of graphics.

It is apparent that most of the research work done on still pictures was mostly related to prose reading. The apparent contradictions concerning the effectiveness of pictures in reading require cautious interpretation. It is clear that there are contexts where pictures do not facilitate learning due to distraction effects and the inability of some learners to shift attention from pictures to text. However, ample contexts exist (e.g. Levin & Lesgold 1978) where pictures appeared very useful in facilitating reading achievement. Dominant conclusions drawn from the work on stills are: (1) pictures are superior to words for memory tasks; (2) adding pictures to prose learning facilitates learning, assuming that the pictures are congruent to the learning task; (3) children up to about the age of 9 or 10 rely more heavily on externally provided pictures than do older children; (4) children do not automatically or spontaneously form mental images when reading.

There is even less literature relating electronic stills although the electronic world of information is increasingly dependent on visual images, colour and mixtures of printed text, moving images and brief "gloss notes" that point to fuller bodies of information. Few textbooks or materials selected for use in school reflect these changes; few teachers understand how to interpret the realities of electronic media in the teaching of reading and writing (Heath 2000). These come in the form of radically different textbooks and programs that stress learning in the arts. For example, *Seeing Writing* (McQuade & McQuade 2000) is a textbook on the teaching of writing and reading that stresses reading visual and verbal texts and brings to a meta-level of understanding just what is required to process multiple forms of information across media. Kress & van Leeuwen (1996) recorded the scholastic movements towards "visual literacy" and the reading of meaning in complex symbol systems beyond the alphabet script. There were many definitions of the term, influenced by many people's perception of the concept. Braden & Hortin (1982), defined "visual literacy" as,

"..... *the ability to understand and use images and to think and learn in terms of images.*" (pp. 41)

Having incorporated the critical factors of visual language, visual thinking and visual learning, the author felt that Braden & Hortin's attempt seemed to be most complete in terms of both form and content with respect to the discussion on hand. Avgerinou & Ericson (1997) in their review of visual literacy pointed out that the way people learn, and subsequently remember, bore a strong relationship to the way people's senses operate and that educators could not afford to ignore the fact that a very high proportion of all sensory learning is visual. Hence, they concluded that educators should concentrate and exploit the visual sense through the nurturing and development of visual literacy, especially with the pervasiveness of visual mass media and computer technology that is so common today.

The review of literature on still visuals reveals the following:

- Below average students had difficulty shifting attention from picture to the written word.

- Visuals have a potentially distracting nature. There is a need to evaluate whether the visual is necessary.

- There is a maturation effect; students' dependence on visuals is less, as they get older.

- People need time to interpret highly realistic visuals.

- There is evidence to suggest that visual thinking plays an important part in skills associated with syllogistic reasoning. However, very little research is available on affective effects of graphics in higher order thinking.

- Pictures are superior to words for memory tasks; however, the pictures must be congruent to the learning task in order to be effective.

- Literature on still visuals were mostly in non-computer context. Issues discussed in the literature were often found to be contradictory.

- Educators should encourage visual literacy, as a very high proportion of sensory learning is visual.

2.1.2 Animated Visuals

Similar to the research on static visuals, early results in instructional animation research were generally negative, and prone to confounding on many counts. The more recent work has begun mapping out some of the conditions under which animation can effectively aid learning. Given the available research, it seemed clear that animation exerts a relatively subtle influence on learning and that many factors can further undermine this effectiveness. Despite recent advances in applying learning and instructional theory to computer-based instruction (CBI) design (Jonassen 1988), however, it was surprising to find that little is known about some of the computer's most fundamental presentation and interactive components. Although there were many additional applications of animation beyond presentation and practice, there was very little research on them.

Animation is a good way to gain the attention of a student and also to cue a student to attend to the most critical features of a screen display. As explained by Gagné (1985), attention gaining is an important initial event of instruction. The most direct application of animation in instruction is using it to present lesson content. Animation, with or without accompany text, offers many opportunities for presenting or elaborating facts, concepts and principles. The processing partnership between visual and verbal information has been well established theoretically e.g. Paivio's (1991) dual coding theory. One could describe these instructional uses of animation as "learning-by-viewing" approaches (Reed 1985). Although not as "cleanly" definable as when used in a presentation strategy, animation has been frequently used in a wide array of interactive activities. The goal of these activities usually involved practicing a recently learned skill, or acquiring a new skill. These could range from highly structured to discovery-based activities and approaches. In questioning strategies, animation was often used as visual reinforcement to student answers.

The previous section, 2.1.1, discussed many issues to be considered when interpreting the results (or lack thereof) of educational research in general, and static visuals in particular. Before any graphic can offer the potential for increased learning, *a need for external aids to visualisation must be established.* For example, before evaluating the effectiveness of a picture, reviewers (Dwyer 1978, Levin, Anglin & Carney 1987) have stressed the importance of first determining whether a textual passage alone elicits adequate internal imaging by students. If students adequately image internally, then the inclusion of external visuals would probably not result in any additional learning gains. Research in section 2.1.1 has shown that adding such visuals may potentially cause unnecessary distraction. Even if the text does not sufficiently induce appropriate (and necessary) mental imaging, visuals must be congruent, relevant and consistent with the information presented in the text in order to be effective (Levin & Lesgold 1978). Lessons learned from static visual research are believed to be relevant for animated visuals, as well.

Hence, extrapolating a learning effect on the basis of externally provided animated visuals seem to depend on two things. First, animated visuals, like static visuals, must pass the test of a "need for external visualisation" and second, the learning of the content must depend on understanding either changes to an object over time (i.e. motion) or changes in the direction to which the object is moving (i.e. trajectory), or both. If there were no case for this second requirement, then there would be no reason why animated visuals would aid learning more than static visuals. In fact, a case could be made that the additional (and unnecessary) characteristics of motion and trajectory could be distracting in some way to the learner. It would also be reasonable to expect stronger learning effects when both motion and trajectory attributes are essential to understanding a certain fact, concept or procedure or in solving a problem. Unfortunately, several early reports of animation research failed to meet these requirements. In fact, two studies frequently cited as "proof" of the ineffectiveness of animation in instruction fall into this category. The first (Moore, Nawrocki & Simutis 1979) contained serious methodological problems in the study's overall design. Subjects in all treatment groups were required to answer review questions after each of four lesson parts. They could not proceed through the lesson until they achieved at least 85% performance level. Obviously, this meant that by the time subjects reached the post-test, all would achieve at least the 85% performance level. Not surprisingly, there were no significant differences between treatment groups on the post-test because of this artificially induced ceiling effect (i.e. that all students learned the maximum amount regardless of treatment). There were also several serious problems in the design and execution of a second (King 1975) frequently cited study. The materials were not sufficiently difficult, which probably also resulted in ceiling effects. The test materials were also heavily weighted to measure verbal kinds of information and thus may not have been sensitive enough to parts of the lesson demanding active visualisation on the part of the students. Finally, the actual graphics used were very crude. In addition, both of these studies used an adult population and neither provided any evidence to indicate that visuals of any type were needed to learn the material. Accepting these studies as conclusive evidence for the inability of animation to promote learning is unacceptable.

Results from more current studies were mixed. For example, a study by Caraballo (1985) on teaching subjects how to compute the area of a polygon found no differences in similar treatment groups, even though care was taken to validate a need for external visualisation through prior field tests. However, it turned out that the animation that was actually produced did not specifically teach the mathematical rules, but only indirectly showed relationships between various geometric shapes, for example, the program demonstrated how two identical triangles could be combined to form a parallelogram. Thus, the addition of animated presentations of these relationships probably had little effect on learning. Also, since both studies used an adult population, the subjects may have already been able to form internal images of the content, thereby reducing any benefit of the animation. Pressley (1977) showed that there was a maturation effect in that people differ in their ability to form and use images, as they grow older.

Rieber 's (1990) study on using computer-based animation in teaching physics (specifically, the subject of Newton's Laws of Motion), in contrast, showed that students receiving animated graphic presentations learned more than students receiving static graphics or no graphics. However, this result was only valid when students also receive practice, an additional factor, suggesting that animation was effective when students were allowed some other form of support with the animation. Successful practice strategies, such as questioning techniques have a long history, especially for lower-level learning such as recall (Anderson & Biddle 1975, Hamaker 1986). Practice enhances learning in these situations by increasing overt attention to and rehearsal of relevant lesson information, combined with positive reinforcement and informational feedback (Kulhavy 1977, Schimmel 1988). Practice strategies that promote higher levels of learning were shown to demand different design assumptions (Salisbury 1988). Learning is promoted by presenting problems or conflicts that encourage a student to use novel and original strategies, such as hypothesis-testing or experimentation, to derive solutions. Rieber, Boyce & Assad (1990) then replicated the experiment on adults. No differences were found, but the subjects' response times on the post-test indicated that those who received the animated presentations took significantly less time to answer the questions. This suggested that the animated presentations might have encouraged mental organisation of the material as it was assimilated. The implication is that although the adult subjects were sufficiently able to internalise the image, allowing all groups to achieve similar performance levels, the externally provided animated displays aided the learning process, even though the performance measure was unable to detect such differences.

Mayer & Anderson (1991) showed both the range and limitations of adult learning from animated presentation. Subjects were taught how a bicycle pump works. In three separate experiments, some subjects watched only an animation of the principles, others heard a narration of the same information but without pictures and yet others saw both the animation and heard the narration either together or with the narration coming before the animation. Students given the animation along with the narration significantly outperformed students who either in isolation watched the animation or heard the narration or who heard the narration right before seeing the animation on the problem-solving tasks. Even more important, the animation without the verbal description was completely ineffective, as students in all this treatment compared equally with students provided with no instruction at all. This indicated that students were either unable to appropriately focus on or to understand the most important visual parts of the presentation. Another study by Rieber (1991) also showed that animated presentations would only be more effective than static visuals when students were properly cued to the information contained in the animated sequence. Consistent with Paivio's (1991) dual coding theory, learning from animation, like any visual, is best when paired with appropriate support because of the increase to both representational and referential encoding. This implies that students should be sufficiently guided and cued in order to take full advantage of the potential of animation.

A study by Reed (1985) investigating the use of graphics in teaching algebra word problems suggested that students who were beginners in an area have great difficulty perceiving differences from animation when only required to view the displays. In his study, the animated displays were only effective when paired with an interactive strategy that forced students to attend to critical features of the animated display. Relevant and sustained student interactivity has been one of the most critical features of instructional design espoused by Gagné (1985), Gagné, Briggs & Wager (1992), Jonassen (1988).

The review of animation literature on learning reveals the following points:

- Despite the popularity of animation among computer-based instruction (CBI) designers and developers, little research is available on its effectiveness.
- Early animation research was heavily prone to confounding variables.
- In order for animation to be effective, there must be a need for external visualisation of changes to an object over time (motion attribute) and/or in a certain direction (trajectory attribute).
- Children and adults vary in the degree to which they benefit from animated displays, reflecting a maturation effect.
- Novice or beginners have greater difficulty perceiving animated displays.
- Learners may need to be carefully cued or supported in order to benefit from an animated display. Animation on its own without any form of support is ineffective.
- Effective practice strategies such as rehearsal of relevant lesson information, combined with positive reinforcements and feedback can lead to improved learning.

2.2 Virtual Reality and Virtual Environments

Real-time animation occurs when the computer is able to display graphic frames in a quick enough succession to produce the illusion of motion. Real-time animation permits computer applications such as video games and simulations. Simulations, both of real and imaginary things are often referred to as "micro-worlds", a term coined by Papert (1980), of realities or fantasies where a user goes to experience something firsthand. Micro-worlds are primarily exploratory learning environments, discovery spaces and constrained simulations of real-world phenomena in which learners can navigate, manipulate or create objects and test their effects on one another. Hanna (1986) says, "Micro-worlds present students with a simple model of a part of the world", which allow learners to control these phenomena and to construct deeper level knowledge of the phenomena. The idea associated with this approach is the feeling of "direct engagement" - the feeling that the computer is invisible, not even there; what is present instead is the world being explored (Draper & Norman 1886, Reiber 1992).

By combining technologies, the illusion of leaving the real world and stepping into another computer-generated one was possible in the late 80s to those who could afford the technology. The roots of VR in training and education can be traced to computer-aided design (Sutherland 1965) and the development of head-mounted devices (HMDs) for use by fighter pilots (Furness 1986). The point of these early projects was to place participants in environments that provided them with just the information they needed and with which they could interact as naturally as they could with the real world. This required total immersion by viewing through the HMD, which also acts to isolate the participant from the real world. There was also the necessity of tracking the position of the participant's body and implementing transducers to interpret the participant's natural behaviour (such as pointing and looking) and commands. Virtual reality became more affordable and thus the use of the technology became more widespread in the early 90s. Towards the late 90s, it was possible to bring the virtual environment down to the desktop level running on the personal computer for the purpose of education (Tan & Ward 1998, Francis & Tan 1999, Tan 2000). VR can either be immersive, in which the user wears a head-mounted display unit, or a "window on the world", in which technology simulates a three-dimensional environment on a two-dimensional screen (McLellan 1996). Ruddle, Payne & Jones (1999) have showed that despite the user interface differences, experimental studies have not shown a significant difference in effects between the two different VR technology for navigation tasks. Byrne's (1996) study found that for eleventh grade students learning the structure of atoms, there was no difference between students in the immersive and non-immersive conditions. It should be noted that this study tests conceptual understanding rather than recall. Salzman et. al. (1999) compared an immersive 3D environment to an interactive 2D learning environment. In that study, they found that students using the immersive 3D environments were better able to define concepts but the differences in outcome were still statistically not significant.

So what makes VR potentially important as a learning environment? Osberg (1993), one of the researchers using VR for education in the University of Washington's Human Interaction Technology Laboratory felt that it was the sense of immersion and inclusion in the virtual educational environment that may allow the student an opportunity to interpret and encode his or her perceptions from a broader, deeper set of experiences compared to those that can be had in the "standard" educational environment.

Ferrington & Lodge (1992) go on to say that:

> *"The environment, when effective, invites user participation in problem solving, concept development, and creative expression ...... Though we can only speculate on the contributions virtual reality will make to education, it seems, from emerging evidence that students will participate in responsive environments in which they will become engaged in full body-mind kinaesthetic learning. Such learning will combine cognitive, affective and psychomotor skills as students pursue their own learning strategies." (pp. 16-17)*

In literature, there were many ideas concerning how VR could facilitate learning, including: visiting inaccessible places or historical scenes (Newby 1993); manipulating simulations of the real world, without the danger, expense or time consumption of doing the real thing (Pantelidis 1993, Tan & Ward (1998), Tan & Chu 2000, Tan 2000); exploring places and things more effectively because of alterations in scale and time (Stuart & Thomas 1991); learning algebra in a virtual world where the behaviour of objects demonstrates the axioms of algebra (Winn & Bricken 1992). However, there were fewer examples showing how students learn in VR and which features in VR provide the most leverage for enhancing understanding. On top of that, most of these studies were conducted without proper empirical framework, with an emphasis on effects rather than on causes, providing little useful information for future work. The above examples do nevertheless have common assumptions about using VR in schools. These assumptions about potential educational benefits were either unique to VR, or less evident in other media. Three assumptions in particular are prominent, and they focus on VR's impacts on spatial thinking, interest level and individual learning.

2.2.1 *Spatial Thinking*

Erickson (1993) has shown that spatial metaphors can enhance the meaningfulness of data and provide qualitative insights. Numerous researchers have implicated spatial ability as one of the strongest predictors of performance in mathematics and science (Halpern 1992) and affects mental manipulation, a process important to scientific reasoning (Hegarty & Sims 1994). It was felt that this opportunity for developing what Gardner (1983) terms spatial intelligence could be fostered through virtual environment creation and experience. Similar to findings in research on static and animated visuals, early results were generally negative and prone to confounding. McLellan (1994) argued that VR has particularly strong potential for learning, which involves spatial thinking. She suggested that learners can use VR to explore perspective and spatial relationships, and referred to existing architectural applications as an illustration. These VR applications allowed clients to take a virtual walk through a building, while still in the design stage, to give feedback to the architect. She argued that clients usually find it more difficult than architects to visualise buildings from two dimensional plans because their spatial thinking was not as deeply trained, and a 3D VR presentation would enhance the clients' understanding. Similar findings were found in various immersive spatial navigation studies (Arthur et. al. 1996, Witmer et. al. 1996). Regian et al. (1992) distinguished between small-scale space, which can be viewed from a single vantage point at a single time, such as the front view of a building, and large-scale space, which extends beyond the immediate vantage point, such as the set of plans of a building. They felt that VR was suitable for large-scale space illustration because the technology allowed views from different vantage points. They argued that because VR is three dimensional, it could eliminate the need for translation from 2D to 3D. However, in the education arena, it could alternatively be argued that the direct elimination of the need for translating from 2D to 3D, could lead to students losing their practice of this translation cognitively, hence dispossessing them of a chance to pick up this technique. . It would have been more appropriate to argue that the ability to observe phenomena from multiple viewpoints aids understanding and that the visual, auditory or even tactile cues could be used to help students focus on important information as Salzman et. al. (1999) had done. It was felt that Regian et. al. could also have provided more empirical evidence of how eliminating the need for translation could have aided the development process of spatial thinking to fully convince the reader

In exploring VR's impact on aspects of spatial thinking, Ainge (1996a) compared upper primary school students constructing and exploring virtual 3D shapes with a control group which built shapes from card nets. Desktop VR was used in this experiment. In pre- and post-tests, students drew specific shapes from memory, drew shapes according to how they might look from various viewpoints, and pointed out shapes used in everyday objects. Students in the VR group used the VREAM program to construct a simple virtual world consisting of a cube, rectangular prism, triangular prism, square based pyramid, triangular based pyramid, cone cylinder and sphere. They then explored these shapes by flying around them, zooming in and out, and going inside, as they chose. The VR experience did not, however, have a significant impact on being able to draw 3D shapes from specified viewpoints. Not only were the differences between experimental and control groups not significant, gains between pre- and post-test were small. However, Ainge reported that the VR group did become significantly better at pointing out shapes in everyday objects. The impact of VR on this aspect of spatial thinking is important, because students need to be able to generalise classroom knowledge to the outside world. The result is intriguing because it would seem reasonable to assume a fundamental link between visualising shapes from various viewpoints and recognising shapes or parts of them in everyday objects. However, the negative results obtained were not surprising. Animation literature in section 2.1.2 as well as studies by Luetner (1993) on discovery learning using simulation seem to indicate that in order to gain domain specific knowledge from simulation, the learner has to be supported or cued by making explicit basic concepts, facts, rules and principles of the simulated domain of reality, implicitly given in the simulation, but which the learner alone would be unable to discover because of inappropriate exploration. There was no evidence of such support in Ainge's research. It was also felt that the experiment was badly designed. In the experiment, it was not clear what particular characteristic(s) of VR contributed to the skill of recognising shapes in everyday objects that was not available to the control group children who worked with card models. The task could be too simplistic, hence producing a ceiling effect. Viewpoints could be found in the completed card models by simply rotating the object, instead of flying around the viewpoint. This experiment seem to suggest that learning in VR was also related to the finding in animation literature which showed that in order to be effective, there must be an established need for using the media. In this case, there was no advantage of using VR over the card net model.

Unlike Ainge, Salzman et. al. (1999) verified the need for using the VR technology by choosing the difficult concept of electrostatics: electrical field (force) and electric potential (energy) in their study. Electrostatics concepts are three-dimensional, abstract and have few observable real-life metaphors. The domain expert in the field indicated that learners have trouble visualising the phenomena and often confused the concepts of forces and energy, demonstrating that they do not understand the true meaning of the representations that are traditionally used. Hence, Maxwell World, the electrostatics learning environment in 3D was created. All of the students involved in the study had basic knowledge of the physics of electric fields having completed at least in introduction to electric fields in their high-school physics. Pre- and post-lesson knowledge assessments showed that both groups demonstrated significantly better understanding in the post-lesson assessments. However, students developed a significantly more in-depth understanding of the distribution of forces in an electric field, as well as representations such as test charge traces and field lines while using Maxwell World. Students in the 3D group were better able to define concepts than students in the 2D group. Also, after a 5-months period, students in the VR group were better able to describe electric fields than the 2D group although the results were not statistically significant. However, it was felt that this study with a sample size of only 14 students might be too small to draw a conclusion.

In another study of upper primary students, Ainge (1996b) compared recall of details in a virtual scene with recall of details from a series of photographs of the scene. The scene was a single furnished room which the students explored at will. The intuitive expectation that a sense of actually being in the virtual room would enhance recall of all details better than photographs was not supported. The students remembered which objects were in the room, and their colours, just as well from studying the photographs. Although the students were new to VR, were enthusiastic, and made comments about enjoying it, their enjoyment did not lead to better recall across the board.

However, VR had a significantly stronger impact than the photographs on students' recollection of numbers of each object (for example, there were four dining chairs) and location of objects relative to each other. There was no indication as to how VR enhanced recall of numbers of objects. The interaction, practice of navigation, may have helped but data on this was not collected. The photographs consisted of multiple views of the room and showed the objects just as clearly as the virtual scene. Some children however, made comments while studying the photographs, which indicated how VR might have helped them to remember positions of objects. Although the verbal instructions made clear that the 18 photographs were all in a single room, some students revealed that they were visualising more than one room. In VR, it was possible to see at a glance that there was only one room, but some children clearly had difficulty in synthesizing the photographs into a whole. The findings are similar again to animation literature, especially the bicycle pump example (Mayer & Anderson 1991) discussed in section 2.1.2. Ainge's experiment confirmed that "narration before the static visuals" and correspondingly, "VR without narration" was ineffective. Hence, the same conclusion could be drawn - that there must be a contextual cue for learning to occur.

2.2.2 Interest Level

Dede (1992) suggests that virtual worlds could strongly motivate learning by stimulating fantasy, challenge and curiosity. Lewis (1994) offered the view that children would be motivated to learn in virtual environments simply because they will enjoy the experience. Pantelidis (1993) argued that VR was highly motivating, because it was almost impossible for a student using a VR program to be passive and Heeter (1992) suggested that users develop the subjective impression that they were participating in a "world" that was comprehensive and realistic enough to induce the willing suspension of disbelief.

Bricken & Byrne (1993) from the Human Interaction & Technology Laboratory, University of Washington introduced 10-15 year-olds to immersive VR at a science summer camp. Each group worked intensively with VR for one week. Using SWIVEL 3D they designed, built and explored virtual worlds. In an opinion survey, the students reported being very pleased with the experiences. However, in an earlier study, Osberg (1993) from the same institution and using the same equipment but looking at both the incentives and disincentives of using immersive VR observed that 8-16 year-old students suffered from "symptoms of simulation sickness, including nausea, visual fatigue and spatial disorientation" due to the "cue conflict" of wearing a head mounted device. Over 40% felt between somewhat sick and very confused or disoriented and 13% felt somewhat sick to their stomach and 20% felt somewhat nauseous. Two children were actually ill after removing the headset and there were several others who experienced headaches and general disorientation. One child was disoriented for 12 hours after the experience. Salzman et. al. (1999) in a later study also indicated that all students in their experiment (high-school students) experienced some form of simulator sickness (oculomotor discomfort in particular) after wearing the HMD for 1.25 hours, even with breaks in between. They reported that the simulator sickness problem appeared to distract users from the learning activities and to contribute to fatigue. In their experiment, most students experienced nothing more than slight eyestrain; however two students experienced moderate dizziness and nausea during the first session and consequently did not return for the second session. It was felt that this was an important aspect of the interaction experience and could lead to decrease in motivation. It was felt that this was not highlighted in the Bricken & Byrne study. However, it would be fair to say that Osberg did not point out in her article which student age group were the ones affected by the simulation sickness. It could be that the Bricken & Byrne study, having a narrower age-gap at the upper range, experience none or less of such problem.

Osberg (1995) visited a range of schools and introduced over 2,900 children to VR by means of a brief hands-on demonstration, in addition to more intensive work with a further 36 students. Osberg reported that the novelty of the technology appealed to the students and they were anxious to be involved. More significantly, it was found that interest remained high even after several experiences, without any sign of reduction. Osberg reported that students who became involved at the level of building their own worlds became highly motivated, and displayed a powerful sense of ownership and desire to share their achievement. They also displayed higher motivation and more positive attitudes towards science and technology. Nevertheless, she found that, although children in the 16 to 18 year age group enjoyed VR, their enthusiasm was noticeably less than primary students displayed. Hence, there is an indication that as their age increased, students displayed a lesser degree of enthusiasm and motivation towards learning using VR.

Ainge (1996a), in the study of VR's impact on learning about three dimensional shapes, found that the children, who normally tended to participate reluctantly in classroom activities, maintained enthusiasm over a period of six weeks. The teacher was impressed by the high level of student engagement and enthusiasm, which contrasted sharply with the response to other classroom activities. Each student was interviewed at the completion of the study, and responses indicated a unanimous feeling that VR had helped them learn, a high level of enjoyment of VR, and strong maintenance of interest. Fifteen students reported after six weeks that VR was at least as enjoyable as when they first began and seventeen said that they preferred learning with VR rather than other activities.

Pentelidis (1995) led a group that produced virtual reconstructions of a native North American Indian fort, using VIRTUS WALKTHROUGH. Middle School students were given a lesson about the fort, and then explored the reconstructions. Pantelidis reported that the children were very enthusiastic and wanted to find out how the Indians had lived.

Ainge's (1996a) and Pentelidis's (1995) articles are but two of many such articles (Moshell et. al. 1993, Grigson 1995, Brown et. al. 1996) describing students' enthusiasm and motivation in learning with VR. All these articles did not refer to literature on motivation but rather gave description of effects. For example, in Ainge's case, were the students' difficulty level of using the VR medium or the perceived difficulty level of the students' personal task motivating factors? Clark & Sugrue (1988) found that the use of the media and the perceived difficulty of tasks affect the motivation level. If it was pitched too high or too low, lower motivation could occur. This argument is reflected again in Salzman et. al. (1999) which showed that the interaction experience was an important factor which could help or distract students from learning activities. Luetner's (1999) study on guided discovery learning showed that students with low self-confidence seem to be hindered by adaptive advice with regard to the acquisition of functional knowledge whereas students with high self-confidence profit by adaptive advice. Luetner further reported that students with low self-confidence seem to pay more attention to adaptive advice messages in the sense that they convert them less into functional knowledge, but more into verbal domain knowledge and the opposite seems to occur in the case of students with high self-confidence. This is again similar to Samuel's (1967) findings for static visuals. Samuels found that students, usually poorer students, had difficulty shifting their attention from a picture to a written word because the picture required less effort. Currently, there is little or no literature available to bridge the use of virtual reality in education to motivation theory, for example the relationship between learning in VR and the self-efficacy theory of motivation (Bandura 1978), the mastery-oriented behaviour (Dweck 1986, 1991) in students, or discussion of student enthusiasm using Kearsley & Shneiderman's (1999) engagement theory or Czikszentmihalyi's (1990) optimum experience of "flow".

2.2.3 Individual Learning

Pantelidis (1993) points out that the high level of interaction required by VR is also highly individualistic, because the user decides what to do. According to Ferrington & Loge (1992), when students actively pursue their individual strategies for exploring virtual scenes, they should learn better than when they take a passive role in the classroom. They anticipated that learning would combine cognitive, affective and psycho-motor skills as students pursue their own learning strategies. Winn and Bricken (1992) argue that a strong point of the free interaction with virtual scenes is that it gives students the opportunity to explore the same place repeatedly, thus building their understanding. Kelly (1996) argues that VR as an educational tool has very little in common with the teach-test-correct programs of traditional computer aided instruction, and provides opportunities for students to construct their individual learning. In virtual environments, students can become part of a phenomenon to experience it directly or alternatively, step back from the phenomenon to allow a global view of what is happening. According to Wickens & Baker (1995), this deepens learning by providing different and complementary insights.

Cromby, Standen and Brown (1995, 1996) used a virtual supermarket to teach shopping skills to students with severe learning disabilities. Apart from finding that after the VR practice, the students were significantly faster and more accurate in real world shopping, they investigated change in self-directed activity. They found that over the period of the VR session, there was a significant decrease in teacher input, and in particular, instruction and physical guidance decreased at a faster rate than more open-ended assistance. The use of VR practice in this case seems to promote self-directed activities. Also, this shows that skills learnt in VR could be transferred to the real world. Other literature also indicated that skills could be learnt in VEs and transferred to the real world (Loftin & Kennedy 1995, Regian, Shelbilske & Monk 1992, Hays & Vincenzi 2000, Rose 2001).

Ainge (1966a) observed that students explored their shapes worlds in individual ways. Some of the students in the study moved about slowly, as if they were cautious and sometimes were startled by movements. The boys tended to make more rapid movements than the girls, although this did not apply in all cases. The students also had different ways of navigating the virtual world, some preferring to use a virtual "hand" controlled by the mouse, while some preferring to switch the virtual "hand" off. Also when a mistake in navigation was made, some students recovered by recalling and reversing the last movements while others had no strategy other than random movements or calling for help. This seems to indicate that interaction is highly variable and dependent to some extent on individual learner characteristics.

Winn et. al. (1999) and Osberg (1997) also described experiments where students learnt as they built virtual environments. However, it was felt that although this method is useful for children constructing simpler concepts, older students constructing difficult concepts at the tertiary level may need more time in their learning (Tan, Zhu and Zhou 2002). Winn et. al.'s research also showed that constructing VEs only helped lower ability students. However, the sample was small, and experimental controls were not possible in the project and the finding needs to be replicated in a controlled experiment.

An interesting study was conducted by Antonietti et. al. (2001) on the use of desktop VR to help undergraduates understand the structure and functioning of a turning lathe. In the experiment, students were treated to two main categories of training sequentially. The first consisted of studying hypertext information of the structure and functionality of the lathe, followed by navigating and interacting with a VE of the lathe. The second experiment consisted of navigating and interacting with a VE of the lathe, followed by studying the hypertext information of the domain area. They found that novice students (non-engineering students, age 20 to 26) from both groups did not encounter difficulties understanding the core concepts of the structure and functioning of the lathe even though some errors occurred. Presumably, whereas experience with the VE was enough to yield an overall understanding of the machine, such an experience did not induce more sophisticated learning outcomes, closely linked to a technical terminology. The pre- and post-test results showed that, although not statistically significant, novice students did better in the VE-Hypertext mode. Expert students (engineering students, age 20 to 26), however, showed significant improvements between the pre and post test results in the representation of the architecture and functioning of the lathe. Although statistical analysis failed to support the existence of significant differences between the VE-Hypertext and Hypertext-VE mode, the trend in the data showed that information provided by the Hypertext-VE mode was better assimilated. This was exactly the opposite of results gleaned from the novice students. Trends recorded suggested that novice students' learning is enhanced when the exploration of the virtual lathe precedes the presentation of hypermedia information. Conversely, as supported by the results in the study using expert (engineering) students, it is better to begin to explore the hypermedia and then to navigate the virtual environment. Presumably, in the first case, students lacked any idea about the lathe. Thus, the concrete experience provided by the virtual machine gave them the opportunity to acquire a general concept sketch, which is useful to understand and organise information subsequently by hypermedia. If notions are provided without such a preliminary mental framework, it is difficult to make sense of them. This seems to echo the thoughts of a team of researchers in Vanderbilt University (Cognitive & Technology Group at Vanderbilt, CGTV 1992a) working on issues of learning technology. They write that:

> *"Because the novices have not yet been immersed in the phenomena being investigated, they are unable to experience the effects of the new information on their own noticing and understanding." (pp. 79).*

This apparently is a constructivist approach(see chapter 3 for details). In the second case, learners already had a model of the lathe; they did not need to acquire preliminary reference points; for these students learning required linking abstract notions to real elements. For this reason, they performed better when the interaction with the virtual lathe followed the hypermedia exposure: in this way, in fact, they could find the parts mentioned in the text in the 3D simulation of the machine and they could see how the operations described verbally can actually be applied. From the above, it can be seen that understanding requires students to be able to represent parts of the lathe correctly assembled and to identify their functional roles. In fact, from the description given by Antonietti et. al., learners must know not only how the lathe is arranged (the kind of knowledge involving physical and spatial relations) but also how it works (and this involves temporal, dynamic and causal relations). Thus, since this type of understanding includes procedural aspects, relevant sources of information are not only notions and concepts acquired through reading text and viewing pictures, but also trials and feedback experienced through action. In Antonietti et. al.'s study, both kinds of sources were available because hypermedia provided concepts and VR gave the opportunity for a motor-perceptual way of learning. However, a limitation was that there was no discussion in the article regarding collaboration. In a normal class, students would be sharing and discussing their findings. Was there only individual learning or were there discussions between the students? If there were, how was VR used? It is again felt that sample size for the two cases were too small (15 novice students and 12 expert students) for drawing a conclusion. It is also quite clear that the experiment described was not meant to replace teachers, lectures, exercises and so on but to augment the lessons.

Another theme common to learning using VR is constructivism (see theory of constructivism in chapter 3). Educational theory and cognitive science support the exploration of VR as an educational tool. In the field of educational theory, the concept of constructivism powerfully articulates an effective strategy for teaching children. Its proponents advocate that students should be fully involved in their education instead of playing the role of passive sponges. For example, the direct construction of understanding from interaction with objects and processes in VEs uses 'first-hand' experience (Clancey 1993), instead of knowledge that is interpreted by a teacher or a textbook. Various examples (Brown et. al. 1995, 1997, Roussos et. al. 1999, Winn et. al. 1999) including those mentioned above (Winn & Bricken 1992, Bricken & Byrne 1993, Luetner 1993, Osberg 1995, Ainge 1996a, Kelly 1996) advocate the application of constructivism in designing VEs. The advocacy was due mainly to the matching of the theory with the potential for using VEs. The seven common principles of constructivism devised by Jonassen (1994) for instructional design can be reinterpreted in the light of using VEs in education.

1. **The natural complexity of the real world.** It has been suggested that representing true complexity will aid in the understanding of concepts (Bednar et. al. 1992). In the real world, complex inter-relationships determine how and when certain concepts are used. These relationships can be replicated more easily in a VE than other modelling techniques.

2. **Knowledge construction, not reproduction.** The traditional educational approach is of learning abstract concepts through repetition; it aims to communicate information and then test the success of the communication. Knowledge construction, on the other hand, must be nurtured by its environment; it involves the construction of information learned through exploration, experience and

negotiation (Brown 1989). Rather than simply acquiring abstract facts, knowledge construction can be seen as acquiring the ability to make sense of the situation, and may be demonstrated by the ability to construct plans in response to situational constraints (Duffy & Jonassen 1992).

3. **Authentic tasks.** In the real world, tasks are carried out through direct manipulation or by using symbols that are closely connected with specific activities. These activities can be seen as a means to an end (Brown 1989). VEs can replicate this relationship, using realistic tasks that require skills similar to those which would be used to complete those tasks in the real world.

4. **Case-based rather than predetermined sequences.** Building VEs to replicate their real-world counterparts maximises the assimilation of information applied in real-world situations and hence improves the construction of knowledge. Brown (1989) advises that any learning environments should support student exploration and prescribing activity.

5. **Reflective Practice.** Developing an understanding of an unfamiliar situation by viewing it as something similar to another situation with which the student is familiar allows them to draw upon their understanding and applying it to the novel situation. Reflection on existing mental models is used to infer, explain, and predict a new situation (Jonassen 1994).

6. **Context-depedent knowledge.** Many theorists agree that people are better at acquiring knowledge when it is specific and dependent on context. In their discussion, Duffy & Jonassen (1992) said that context is an integral part of meaning, if a concept is demonstrated in isolation, this may limit the student's understanding of its meaning. This, in turn, will affect the application of the information learned.

7. **Collaboration through social negotiation.** In a good learning situation, students should be able to talk about their experiences and share their explorations. From these collaborations with others, many perspectives may be discussed, thus enabling students to develop and evaluate their ideas. In order to be meaningful, the creation of new understandings must be justified and explained with reference to prior understanding built upon existing foundations (Draper 1995). It should be a

cooperative effort in which students try to understand and develop alternative perspectives. This is important since there is often a large gap between a teacher's and student's understanding (Perret-Clermont, Perret & Bell 1991). The presentation of alternatives supports discussion and its productive value in the construction of understanding (Brown 1989).

Finally, Salzman et. al. (1999) provided a hypothetical model describing how VR's features work with other factors in shaping the learning process and learning outcomes for complex conceptual learning. As shown in figure 2-1, the model, although general, helps highlight important issues and could be refined further to help answer a number of research questions. The model suggests that VR features are likely to influence learning: both the learning process (or the kinds of information to which one attends) and learning outcomes (or the person's level of understanding after lessons have been completed). Additionally, the concept one is trying to understand is likely to moderate how features available in VR influence the learning. In other words, the relative effectiveness of 3-D representations may depend on the concept being learned.

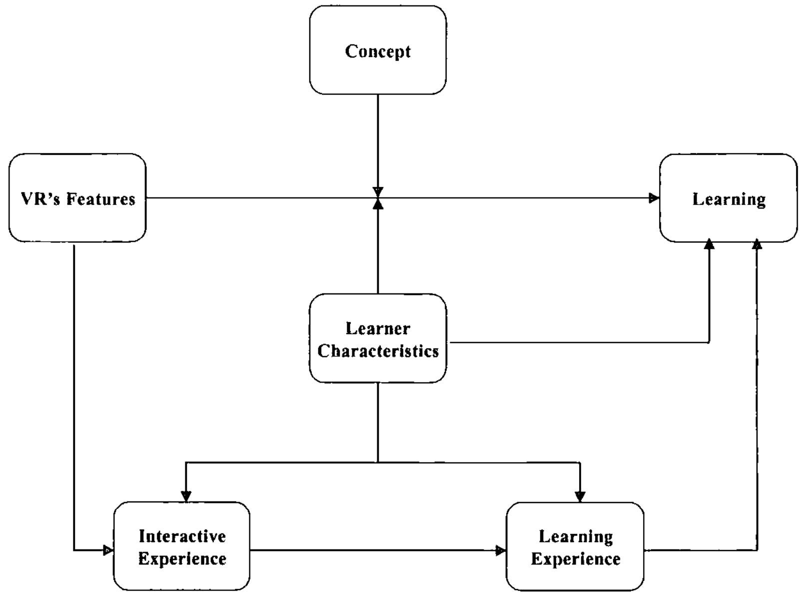

Figure 2- 1: A Hypothetical Model of Learning in VR (Salzman et. al. 1999)

Individual characteristics of the learner, or learner characteristics (e.g. domain knowledge), should play a role in shaping the learning process and may also interact with VR's features in influencing learning. For example, the extent to which a feature supports learning may vary as a function of the learner's domain experience, spatial ability or learning style. Finally, it is likely that VR's scope, as well as its individual characteristics, affect both the interaction experience (e.g. how easily the user can interact with the system) and the learning experience (e.g. motivation, perceived meaningfulness), which, in turn, influence learning. As the model demonstrates, the link between VR's opportunities and learning occurs within a web of other relationships.

Salzman et. al.'s model can be used to further understand learner needs in teaching a particular knowledge domain. Once the concepts are identified, those most suitable for teaching through a VR environment, and which VR's features are likely to facilitate are selected based on learner characteristics and previous knowledge and experiences. The model also holds much promise in helping to identify which of VR's features have promise, which characteristics of the learner require careful attention, and which facets of the interaction and learning experiences play a substantial role in shaping learning outcomes.

2.3 Findings

The potential for developing and experiencing VEs as a learning tool is possible due to the changing educational values outlined in chapter 1. As researchers come to better understand the nature of human intelligence, creativity and the value of being multi-modal in learners' perception, there is an increased awareness of developing visual thinking skills in addition to the more traditional focus on reading and writing. However, lessons from past experiences should underpin this usage of VR and questions should be raised to identify further issues relating to the use of this new technology.

In the use of VEs, the following lessons were identified from the literature:

Experiment & Studies:

- There were many contradictions and often studies were conducted without an adequate empirical framework, and without proper regards to pre-conditions that might affect the usefulness of the results. There were also cases where questionable sample size was used in deriving conclusions.

- There is a lack of literature available to bridge the gap of linking the use of VR with motivation theory. The literature refers to effects rather than causes.

Attribution:

- "Direct engagement" and "inclusion" were seen as main factors by researchers advocating the use of VEs in education.

- Multiple viewpoints and multi-modal cues such as auditory, visual or even tactile messages available in VEs enhance understanding by helping learners to focus on important information.

- Motivation in VR is attributed to a combination of challenge, curiosity and enjoyment.

- Interaction experience can support or interfere with the learning. If the tasks are too difficult or too easy, motivation level may decrease.

- Interactivity in VEs helps learners to learn better due to cognitive, affective and psycho-motor skills involved.

- Older students display a lesser degree of enthusiasm and motivation towards learning in VEs, leading to a conclusion that there is a maturation effect similar to the effect found in the literature on animation.

- Students with low self-confidence are hindered by adaptive cues given in the VE while students with high self-confidence are encouraged.

- Interaction is highly variable and dependent to some extent on individual learner characteristics.

- The availability of the VE for repeated exploration (practice) allows students to construct their individual learning by providing different and complimentary insights and by promoting self-directed learning.

- Practices in VEs promote the transfer of skills from the virtual to the physical world.

- If notions are provided without a preliminary mental framework, novice students find it difficult to make sense of them. Hence, there is a need to relate to the learners' prior knowledge before introducing the learners to a VE. Novice and expert learners construct knowledge differently.

On the Use of VR in learning:

- In comparing navigation tasks and learning of concepts, there was no significant difference between immersive and desktop VR systems. Results also showed that there was no significant difference between 3D and 2D learning environments, although VR's 3D immersive representation was shown to help students develop more accurate and causal mental models than 2D non-immersive representations

- Similar to literature from static visuals and animation, there is a need to justify the need for using VR in education. Complex concepts were preferred over simple ones. A ceiling effect could occur if the learning event chosen was too simple.

- Similar to literature from static visuals and animation, contextual cueing is necessary for learning to occur.

- There is a need to balance the use of immersive VR and learning as long exposure may cause simulation sickness in some students.

- Studies in which students built VR models in their learning involved a longer learning cycle but may lead to better understanding.

- The theme of constructivism is strongly supported in using VEs as learning tools.

- VR features are likely to influence learning: both the learning process (or the kinds of information to which one attends) and learning outcomes (or the person's level of understanding after lessons have been completed). Additionally, the concept one is trying to understand is likely to moderate how features available in VR influence the learning. Learner characteristics, VR's features, interactive experience all play a part in the overall learning process, hence affecting the final outcome.

There is a need to understand the interplay of VR's features, the learning experience, the interaction experience, individual characteristics and learning at a finer-grained level of detail. In doing so, it should bring research one step closer to understanding how VR's features can be used to support the learning of complex information. From the lessons learned from the literature review, the following questions regarding the use of VEs were identified:

- The integration of VR in the classroom as a learning tool is still in its infancy. Though some research has been conducted, there is interest in understanding much more about the educational value of the world-experiencing process. It seemed from the above discussions that cognitive theory should be used to address how VR can help students learn. According to many cognitive scientists (Newell 1990, Johnson-Laird 1988), humans think symbolically, so if abstract information or concepts is presented in the way humans think, learners might learn better. The literature reviewed points out that the constructivist learning paradigm is closely linked to the utilisation of VEs in education. The goal is to design and present authentic learning opportunities in which individuals have the freedom and the opportunity to ground their experience in a manner appropriate to them. How true is this belief? The gap relating motivation theory to features inherent in VR needs to be further explored. Were students really motivated by VR? What was the root cause behind the motivation? Chapter 3 will be used to shed light on these issues.

- Despite the need to learn spatial knowledge, manipulation of instruments and machines, procedures, interactions requiring knowledge of speed and acceleration and problem solving, not many studies have been conducted in the engineering education domain. The pre-conditions for introducing VR into the curriculum appeared to have been satisfied. Utilising a suitable empirical framework, could a study be worked out to incorporate the use of VE in an engineering course to examine outcomes, the features in VR which provide the most leverage for enhancing understanding, and finally how students participate, using theories to predict and explain the observations? Taking into account the findings above, and eliminating factors that would cloud the empirical study, the following key points need to be observed:

- Using desktop VR instead of Immersive VR to reduce cost of hardware, to enable teaching of a standard class size of 20 students, to ease getting used to the interface and finally, to eliminate simulation sickness.

- Select an engineering subject that fulfils the pre-condition of using VR as a tool in teaching. VR should be used with discernment. It should always serve the curriculum, not just be used to occupy the students.

- Use "expert" students who already understand the basics of the subject and are able to use this prior experience to build up new knowledge.

- Have the necessary support on hand at the beginning to ease students into the learning. Integrate VR with other activities, rather than using VR in isolation.

Does individual, affordable desktop VR promote collaborative learning? Certainly, this issue needs to be observed. These observations will be incorporated into chapter 4.

Hence, chapter 3 of this dissertation will further review literature in the area of cognitive learning to shed more light on the underpinnings of learning in VR. Chapter 4 further discusses the research questions based on the findings in this chapter and chapter 3. Finally, the empirical study is designed to address the research questions uncovered.

PART II

LITERATURE REVIEW

3. MODELS OF LEARNING

This chapter continues from chapter 2 where questions relating models of learning in VR were identified. The findings uncovered in this chapter will be used to explain the results associated with learning and predict the conditions under which learning will occur again. The dominant interpretations and the advantages and disadvantages of each model are reviewed. Topics covered will include behavioural, cognitive and constructivist learning theories, perception, attention, memory and motivation.

3.1 Learning Theories

3.1.1 Behaviourism

A historical context is often useful to better understand the implications of learning models. The notion of behaviourism was introduced by Pavlov (Dembo 1994) and Thorndike (1913), whose research in animal behaviour led to findings in human psychology. Watson (1913) promoted the view that psychology should be concerned only with the objective data of behaviour. The study of consciousness or complex mental states, Watson argued, is hampered by the difficulty of devising objective and functional indicators of these phenomena. At some point, one is forced to consider the facts of behaviour. These, at least, can be agreed upon because they are observable by anyone.

In the early days of behaviourism, the concept of association permeated theories about learning. It was assumed that a response (R) came to be established, or learned, by its association with an environmental stimulus (S). Guthrie (1933), for instance, believed that :

"Stimuli which are acting at the time of a response tend on their reoccurrence to evoke that response."

Clark L. Hull believed that responses become attached to controlling stimuli, but some of these stimuli must be internal because it was not always possible to observe an external stimulus for all responses (Leahey & Harris 1989). Thus, in his S-R theory, he proposed intervening variables such as habit strengths and argued that observed behaviour was a function of these as well as environmental variables such as degree of hunger (drive), size of reward (stimulus-intensity dynamism), and so on.

E.C. Tolman believed that behaviour was guided by purpose. According to Tolman (1948), organisms do not acquire S-R bonds simply by contiguity or reward; they selectively take on information from the environment and build up cognitive maps as they learn. This helped to account for latent learning, in which rats who explored a maze for several trials found the food on a subsequent trial as quickly as rats consistently reinforced in the maze. Tolman's cognitive maps and Hull's habit strengths, however, cannot be directly observed. One cannot observe cognitive maps in a rat's mind; they must be inferred from the rat's behaviour. Likewise, one cannot directly observe habit strengths; they must be inferred from the rat's persistence in a learned behaviour.

B.F. Skinner, a major proponent of radical behaviourism, followed Watson's lead in emphasising behaviour as the basic subject matter of psychology (Skinner 1938, 1974). But Skinner's work differed in a fundamental way from Watson's and others' work contemporary with and immediately following Watson. Skinner's approach to the psychology of learning was to set out in search of functional relationships between environmental variables and behaviour. In other words, he believed that behaviour could be fully understood in terms of environmental cues and results. *Cues* serve as antecedents to behaviour, setting the conditions for its occurrence. *Results* are the consequences of behaviour, which make it more or less likely to reoccur. What might go on in the mind during learning, then, is immaterial to understanding or describing it. Skinner argued that theories of learning simply get in the way of collecting empirical data on behaviour changes

(Skinner 1950). He denied, in fact, that radical behaviourism should even be thought of as a theory; rather it is an experimental analysis of behaviour (Skinner 1974).

The formal beginning of modern instructional technology is usually traced to the convergence of Skinner's application of behavioural learning principals to instruction, usually called programmed instruction (PI), and the audiovisual movements of the mid-1900s. Skinner was well known for creating various "teaching machines" designed to deliver highly structured instructional treatments to learners. Teaching machines carefully controlled and delivered predetermined reinforcement schedules during instruction – a skill that Skinner (1958) found teachers largely unable to perform. These teaching machines were highly interactive, but also tended to be quite dull and tedious. PI, though generally effective for lower-level learning such as fact learning, was largely inappropriate for higher-level learning. Many current applications of computer-based instruction are really just extensions of the PI paradigm.

Instructional systems development (ISD) also has its roots in PI. Many PI principles became cornerstones of ISD. For example, the PI principle of *objective specification* was the pre-cursor to behavioural objectives – the idea that the required learner response should be determined in advance in precise, observable terms. *Empirical testing*, the idea that successful lesson components (e.g. appropriate reinforcement, cueing, step size, and so on) could only be determined based on actual field-testing, was the forerunner to formative evaluation (Hannafin & Rieber 1989). The PI movement is often criticized today, especially given the popularity (and potential) of the cognitive movement. It is true that PI had serious limitations in covering the breadth of learning outcomes. It is also true that PI conformed to the behaviourist assertion that, essentially, environments "control" people's behaviours. However, PI remains the first true experiment in seriously attempting to apply learning theory to instructional practice. It successfully fulfilled the criterion that defines any technology – the application of basic knowledge for a useful purpose, and for that reason PI offers many important lessons for future attempts at harnessing other "technologies" for instructional design.

3.1.2 Cognitivism

In contrast to focusing on strengthening S-R bonds, cognitive orientations to learning consider the actual thought processes occurring in between the stimulus and the response as the most important aspects of learning. As early as the 1920s, people began to find limitations in the behaviourist approach to understanding learning. Behaviourists were unable to explain certain social behaviour. For example, children do not imitate all behaviour that has been reinforced. Furthermore, they may model new behaviour days or weeks after their first initial observation without having been reinforced for the behaviour. Because of these observations, Bandura & Walters (1963) departed from the traditional operant conditioning explanation that the child must perform and receive reinforcement before being able to learn. The emphasis in cognitivism is on how a learner selects, perceives, processes, encodes and retrieves information from memory.

Cognitive influences have, for the most part, successfully shifted primary attention from the instruction to the learner (Gagné & Glaser 1987). Cognitive psychology has "persuaded" instructional technologists to accept the need to consider what happens in between the stimulus and response (i.e. cognitive or mental processing) as the most important part of the learning process, despite the inability to directly observe the process. At first glance, this point may seem to be trivial and academic, but in actuality, this is a significant turning point for the field and is especially relevant for instructional designers. Cognitive models, such as the information-processing models (Dodd & White 1980, R. Gagné 1985, E. Gagné 1985), which describe learning as a series of knowledge transformations, starting with the input of information (stimulus) from the environment, and ending with either an output (response) or the storage of the information in memory, or both, have become the focus of instructional design. Cognitive concepts, such as mental encoding and retrieving (Norman 1982, E. Gagné 1985), selective perception and attention (Broadbent 1971, Norman & Bobrow 1975, Anderson 1980, Dodd & White 1980), depth of processing (Craik & Lockhart 1972, Nelson 1977), metacognition (Flavell 1979, Brown 1980, Duell 1986, Gagné & Glaser 1987), and so on, have expanded the range of instructional ideas and have opened up new approaches for identifying and solving instructional problems.

Despite the positive influence of cognitive psychology on instructional design, the skill, task, and procedural aspects of "the model" are still largely retained. Instructional design is still based on achieving the learning objectives identified early in the process (Gagné, Briggs & Wagner 1992). Thus, in general, the goal of any one instructional design is to bring the learner to the point of mastering the learning objectives as efficiently and as effectively as possible. Certainly, a learner's prior knowledge and abilities (Ausubel 1978, Di Vesta 1987, Tobias 1987), needs for achievements (McClelland et. al. 1953, Maslow 1968, Weiner 1990), and interests (Deci 1985) have a major influence on how the instruction is designed. However, most of the major instructional decisions, such as how content is selected, sequenced, structured and presented are usually made on behalf of the learner. Some use the term "neo-behavioural" to define this mingling of behavioural and cognitive philosophies (Case & Bereiter 1984). By following presentation strategies with practice, the lesson information completes a cycle between the instructional materials and the learners – instruction elicits a response from the learners, followed by the instruction providing the learners with appropriate informational feedback about their performance. Practice is viewed as one part of an instructional component (i.e. orientation strategies, presentation strategies, testing and strategies to enhance retention and transfer).

The second interpretation of instructional technology is patterned after a philosophy of human learning and cognition known as constructivism. Constructivists usually define instructional technology as the generation of computer-based tools that provide rich and engaging environment for learners to explore (Jonassen et. al. 1999). The next section will provide a brief overview of some of the main tenets of constructivism as they apply to learning and instruction.

3.1.3 Constructivism

Constructivism has multiple roots in the psychology and philosophy of this century (Perkins 1992a). Among these were the constructive theory of memory (Bartlett 1932), the cognitive and developmental perspectives of Piaget (1952, 1970), (Vyuk 1981), the interactional and cultural emphases of Bruner (1964) and Vygotsky (1981), the educational semiotic of Cunningham (1992a), and the contextual nature of learning (Kintsch 1988, Brown et. al. 1989). In addition to these, constructivist researchers acknowledge the philosophies of Goodman (1984) and the ecological psychology of Gibson (1977) as important influences on their work.

As such, there is no single constructivist theory of instruction. Rather, there are researchers in fields from science education to educational psychology and instructional technology who are articulating various aspects of a constructivist theory. Its use probably stems from Piaget's (1970) reference to his views as "constructivist" because he firmly believed that knowledge acquisition is a process of continuous self-construction. Piaget's theories can be classified in two ways – stage-dependent and stage-independent (Mayer 1983). Most of the attention is usually given to Piaget's stage-dependent theory, which suggests that there are four stages of cognitive development that people supposedly progress through in their lives – sensorimotor, preoperational, concrete operations and formal operations.

However, Piaget's stage-independent theory concerns two assumptions about how internal mental structures are formed (Piaget 1952, 1970). The first is the need for *adaptation*, or the ability of an individual to survive and prosper given an ever-changing environment. The second is *organisation*, which is one's need or desire for a stable or coherent world. These two processes create an internal or intrinsic conflict for people. The goals or needs of one process directly contrast those of the other. Just as one struggles to achieve an "organized world", the environment presents a new situation or problem. Piaget defined a process, called *equilibration*, which explains how people accomplish this "balancing act". Equilibration consists of two mechanisms: *assimilation* and *accommodation*. New information from the environment is assimilated, under an already existing mental structure. For example, a baby who has learned to throw a tennis ball is just as likely to throw an orange or an apple the first time each is encountered. Accommodation, on the other hand, describes the process where the child builds new structures from the existing structures when the new information no longer fits. Thus, the baby soon learns that some round objects are meant to be thrown, but others are meant to be eaten.

Life's everyday encounters with the environment inevitably lead to one natural conflict after another, conflicts that are resolved by assimilation and accommodation. Interestingly, learning can only occur when an individual is in a state of *disequilibrium*, also known as "cognitive conflict". When confronted with new information from the environment, a person naturally seeks to assimilate, or incorporate this information into structures that already exist. The process of accommodation is triggered when new information no longer matches the existing structures, necessitating the formation of new structures. According to Piaget, this process never ends, though the range or breadth of potential new structures that can be formed are linked to the development stage of the individual.

Educational interpretations of constructivism consist of three properties that are closely aligned with Piaget's theories: epistemic conflict, self-reflection and self-regulation (Foreman & Pufall 1988). Epistemic conflict is really just the Piagetian process of equilibration described above. Learning is a result of trying to resolve a problem encountered in the environment that is outside the person's "repertoire". Of course, the conflict may have been "artificially induced", such as a problem presented by a teacher, but resolution can only be achieved by the individual. In the constructivist vernacular, each resolution is a construction. Just because the environment has posed a problem or conflict does not mean that the individual will choose to pursue resolution. If the problem is perceived as too easy or trivial, then the individual will not find the problem worth pursuing. If the problem is too difficult, the individual may simply choose to ignore it. The property of self-reflection involves an individual's deliberate attempt at objectively and explicitly representing reality in response to a conflict. Arriving at a resolution to the conflict involves the property of self-regulation. Cognitive structures are spontaneously restructured according to the mechanism of assimilation and accommodation. Old mental structures become more refined or comprehensive. New mental structures are formed. Once conflict and reflection trigger self-regulation, the individual acts until resolution is attained, either by explaining the new information as another, extended example of something that was already known (assimilation) or by the formation of something new (accommodation).

Both behavioural and cognitive information processing theories of learning emerged from the objectivist tradition. Theorists who write in the emerging constructivist tradition often contrast their ideas with the epistemological assumptions of the objectivist tradition. Objectivism is the view that knowledge is thought to exist independently of learners, and learning consists of transferring that knowledge from outside to within the learner. In contrast, the constructivist theory rests on the assumption that learners construct knowledge as they attempt to make sense of their experiences. Regardless of what is being learned, constructive processes operate and learners form, elaborate, and test mental structures until a satisfactory one emerges (Perkins 1992a). Moreover, new, particularly conflicting experiences will cause perturbations in these structures, so that they must be constructed anew in order to make sense of the new information. This sounded much like Piaget's schema accommodation. Both Bruner and Vygotsky devised similar concepts to account for the changes in children's knowledge as they develop.

Constructivist theorists also adhere to Vygotsky's (1978) notions about the social negotiation of meaning. That is, learners test their own understandings against those of others, notably those of teachers and peers. Although constructivists have described, often in detail, the epistemological assumptions underlying their work, they have been less clear about what models of memory arise from these assumptions. Some works done in these areas were Cunningham's (1992a) exploration of the rhizome metaphor and Bereiter's (1991) new connectionist models. Bereiter argued that concepts, for example,

> *"...are much more like perceptions than they are like rule-defined categories"* (pp. 13)

and that, in fact, it seems likely students do not learn rules at all. What they learn instead are connections, which, to satisfy constraints of experiences and environments, come to resemble rule-based performances.

Again, unlike the objectivist approach that focuses on identifying the entities, relations and attributes that the learner must "know", the constructivist approach to identifying goals emphasizes learning in context. Brown et. al. (1989), for example, argued that knowledge that learners can usefully deploy should be developed. Moreover, this can only be done in the context of meaningful activity. It is not enough for students to acquire concepts or routines that lie inert, even in the face of relevant problems to be solved. Instead, knowledge must develop and continue to change with the activity of the learner. Hence, constructivist ideas that knowledge develops in context is consistent with theories discussed previously, that of situated learning, Bruner's discovery learning and the dialectics of Vygotsky's theory.

As a start to articulating what is meant by "deployable knowledge learned in context", the CTGV (1992a) defined thinking activities as the primary goals of concern to constructivist. Specifically, they named:

"... the ability to write persuasive essays, engage in informal reasoning, explain how data relate to theory in scientific investigations, and formulate and solve moderately complex problems that require mathematical reasoning." (pp. 77)

Perkins (1992a) agrees,

"The basic goals of education are deceptively simple. To mention three, education strives for the retention, understanding and active use of knowledge and skills." (pp. 45).

Other authors have offered variations of these goals. Spiro et. al. (1991) described the need for learners to acquire cognitive flexibility, whereas Culler (1990) spoke of the need to foster poststructuralist thinking, a kind of reflective criticism. Critical thinking and mindful consideration are also among those goals thought to be fostered by constructivist pedagogy.

Dick (1992) however, raised a concern about the lack of attention paid by constructivists to the entry behaviours of students. He stated,

"Designers use analytic techniques to determine what a student must know or be able to do before beginning instruction, because without these skills research shows they will not be able to learn new skills. Why are constructivists not concerned that the gap will be too great between the schema of some students and the tools and information that they are provided?" (pp. 96)

Dick is also concerned that there are no provisions made for the less capable learner and that they will be overwhelmed in such teaching environment.

In response to Dick's concerns, Perkins (1992b) acknowledged the cognitive demands that constructivist learning goals and instruction typically place on learners. Learners must deal with complex problems, and they must "play more of the task management role than in conventional instruction". According to Perkins, however, this simply implies that teachers must coach individual students who lack adequate entry skills. He said:

"It is the job of the constructivist teacher (or interactional technology) to hold learners in their 'zone of proximal development' by providing just enough help and guidance, but not too much" (pp. 163).

Perkins argues that the reasoning is sensible: students are not likely to become autonomous thinkers and learners if they lack an opportunity to manage their own learning. In typical teacher/test-controlled settings, whatever the students may learn about the content, they are likely to get little experience managing their interactions with the content themselves. Cunningham (1992b) commented that teachers must not only coach students who lack prerequisite skills, but persuade those who are unwilling or unmotivated to engage in instruction. Perkins's & Cunningham's arguments are reasonable, but unfortunately, very often appropriate scaffolding is not part of the repertoire of either the teacher or the technology.

One possible way to deal with the lack of pre-requisite knowledge and skills is to identify and ameliorate gaps within the context of the desired problem solving (CTGV 1992b). In other words, a part of solving complex problems involves determining what skills or information a learner needs to know. And learners who discover that, to solve a problem at hand, they must acquire some other skill or piece of information will be more motivated to do just that. Consider, for example, the use of a word processor programme. Chances are that the users do not know all the possible functions and that it is unlikely for a user to take time to learn all the functions. Only when a particular function is needed will the user start learning the routine. Hence, once the need is present, it will be necessary to acquire the skill that will be required to enable the user to meet his goal. The same is probably true for learners involved in solving complex problems like those presented by CTGV. According to them, pre-requisite skills or entry goals, are not necessarily ignored by constructivists, but they are attended to largely in the context of higher order goals.

It seemed clear from the remarks made by Perkins and the CTGV that constructivist learning goals are best met through a variety of instructional conditions that differ from any proposed theorists such as Gagné (1985). Although Gagné does not appear to incorporate the notion of complex learning environments in the conditions for learning, he has written recently about the importance of teaching multiple goals within a context that meaningfully relates them (Gagné et. al. 1992). But it still falls short of the constructivist's call for environments in which learners can experience the full complexity and authenticity of real world problems.

The other issue is one concerning just how constructive one should be. Perkins (1992a) showed that a way to catch the sense of the issues is to draw a contrast between what is called BIG constructivism (for example, CGTV 1992a, Merrill 1992) and WIG constructivism (for example, Rumbaugh et. al. 1978, Cunningham 1992b, Jonassen 1992, Glaserfield 1995). These are acronyms, where BIG stands for "beyond the information given", Bruner's (1973) classic phrase that characterizes how human cognition reaches beyond a reflexive reaction to the "input", and WIG, "without the information given". What this contrast really means becomes clearer in the context of an example by Perkins. Using the BIG approach, seventh graders being taught the distinction between heat and temperature (one of the subtle contrasts in physics that troubles many students) would directly introduce the contrast, using imagistic mental models, perhaps computer based, to clarify it. As a brand of constructivism, this approach would recognise that mere exposure would not suffice. The learners would need the opportunity to work through their understandings in various ways. Accordingly, this means that while presenting the contrast directly, the BIG approach would then engage the learners in a number of thought-oriented activities that challenged them to apply and generalise their initial understandings, refining them along the way. In contrasts, a WIG approach would hold back on direct instruction. The "official" characterization of heat versus temperature would never be offered, or only late in the lesson. Rather, the learners might be presented at the outset with phenomena involving thermometers and the heating of liquids (again perhaps through computer simulations). They would be encouraged to try to explain such phenomena with their intuitive notions of temperature. The learners would be encouraged to devise better models of what was occurring should anomalies (which are bound to appear) transpire. The teacher would scaffold this process, heavily if necessary, but without directly providing answers. Advocates of WIG constructivism argue that concepts are not truly and meaningfully learned in ways that empower learners unless those concepts are in good part rediscovered by the learners. Advocates of BIG constructivism argue that one can generally quite straightforwardly teach concepts, providing the overall instructional experience includes ample occasion for students to function generatively in testing and extending their evolving conceptions and that education given over entirely to WIG constructivism would prove grossly inefficient and ineffective, failing to pass on in straightforward ways the achievements of the past. However, one thing is clear, despite the disagreement in the BIG and WIG camps. The constructivist perspective, whether BIG or WIG, places demands on the educational setting that are not so readily met: Phenomena and construction kits are at a premium, including ones that deal with rather abstract concepts and domains (Perkins 1992a). Coaching-like interactions with learners suit the constructivist agenda better than more conventionally didactic patters of interaction, with the inevitable question being where these coaches are to come from given present and foreseeable teacher-student rations. In these, and no doubt, other respects, information-processing technologies offer special help, because they allow building the kinds of more intimate, supportive, learning environments called for by the constructivist perspective (Jonassen et. al. 1999). Accordingly, together, information-processing technologies and the constructivist viewpoint fashion an image of education much more attentive to understanding and the active use of knowledge skills. This idea was highlighted previously at the end of section 2.2.3 when the use of VR in constructivist learning was discussed.

3.2 Visual Perception and Engagement

3.2.1 Perception and Memory

Visual perception is the process of being able to selectively attend to and then subsequently perceive some meaning from a visual display (Rieber 1994). Levin & Kaplan (1972) have shown that pictures suggesting visual images are effective in facilitating learning. Gestalt psychologists from the 1920s, such as Wertheimer (1923), Koffka (1922) and Köhler (1925), were among the first to be interested in visual cognition and demonstrated that human perception tends to involve insight or "going beyond the information given" in order to construct a meaningful interpretation. Apparently, visual perception is far from an objective process and instead is based on previous knowledge and experiences, using this prior knowledge to guide perception. Solving problems also requires overcoming the effects of past experience on perception. In other words, some problem situations must be perceived in a new way in order for a solution to be reached. Although little is known about how people come to be proficient at casting problems in a new light in order to solve them, there is evidence (Sternberg & Davidson 1983) to suggest that practice on many kinds of problems may help. Practice with a variety of problems can make learners more aware of the role of context in problem solution and thus more open to the consideration of alternate assumptions.

Many studies also show that people's recognition memory for pictures is extraordinary (Shepard 1967, Standing, Conezio & Haber 1970). One theory regarding this "picture superiority" effect is called **dual coding theory**. The theory proposes that long-term memory consists of two distinct, though interdependent codes, one verbally or semantically based and the other visually based (Pavio 1990, 1991). It supports the idea that knowledge is represented on a concreteness-abstractness continuum and that human cognition is predisposed to storing mental representations in one of two forms corresponding to the ends of the continuum. At one end are the visually based representations in which knowledge is stored in concrete and non-arbitrary ways (analogous to analogue information). At the other end are the verbal, or semantic, representations in which knowledge is stored in discrete and arbitrary ways (analogous to digital information). The connection between the verbal and visual system is referred to as referential connections and the activation of informational units within either of the system is known as associative processing. However, processing in the verbal system is believed to be sequential or linear, whereas processing in the visual system is thought to be parallel. For example, a student, in forming a mental image of the refrigerator in his home would be able to "look" left or right, up or down in his mind. Mental "scanning" can be accessed easily or quickly. However, recalling the middle line of the National Pledge of Singapore, for example, would require a linear or sequential search from beginning. Dual coding theory predicts that pictures and words provided to students will activate each of these coding systems differently. The superiority of visual image for memory tasks is explained on the basis of two important assumptions (Kobayashi 1986). The first is that the two codes produce additive effects. This means that if some piece of information is coded both visually and verbally, the probability of retrieval is doubled. The second assumption is that the ways in which pictures and words activate the two codes are different. Pictures are believed to be far more likely to be stored both visually and verbally. Words, on the other hand, are less likely to be stored visually. For example, if a picture of a bus is shown to someone, dual coding theory says the picture provides adequate cueing to the visual memory trace and the individual is very likely to also add semantic labels. Thus, the visual image is being stored twice, once visually and one verbally. Information that is dually coded is twice as likely to be retrieved when needed because if one memory trace is lost, the other is still available. Hence, it could be said that information encoded in both visual and semantic forms with strong and flexible links between the codes should enhance retention, retrieval, and transfer.

3.2.2 Engagement

Chapter 1 described how engagement aids the learning process and suggested that the interactive nature of computer-based learning encourages engagement. Computer games, especially, make use of elements of play to promote engagement. Betz (1995), a proponent of using computer games in education says that increased learning could occur by problem solving in a complex interactive multidisciplinary environment and by "seeing" causal relationships between individual actions and whole systems. So how does visualisation in games or virtual reality system encourage engagement?

Prensky (2001), in his book on digital game-based learning says that computer and video games are potentially the most engaging pastime in the history of mankind. Prensky highlighted some points why games can be used for learning. Play in games arouses intense and passionate involvement. Games have rules, giving structure and context. They have goals, which can be accomplished in phases or stages, which encourage motivation. Games also have outcomes and feedback, encouraging reflection. The adaptive nature of games encourages exploration and problem solving. Finally, games are interactive and visual, allowing learning by doing and ease of assimilation of information.

Laurel (1991) in her research on how principles of drama can be adapted to understanding human-computer interaction gave further insight. She started with an examination of two activities that are extremely successful in capturing people's attention: games and theatre. The basic components of Laurel 's model are:

1. Dramatic storytelling (storytelling designed to enable significant and arresting kinds of actions)

2. Enactment (for example, playing a VR game or learning scenario such as performance)

3. Intensification (selecting, arranging, and representing events to intensify emotion)

4. Compression (eliminating irrelevant factors, economical design)

5. Unity of action (strong central action with separate incidents that are linked to that action, clear causal connections between events)

6. Closure (providing an end point that is satisfying both cognitively and emotionally so that some catharsis occurs)

7. Magnitude (limiting the duration of an action to promote aesthetic and cognitive satisfaction)

8. Willing suspension of disbelief (cognitive and emotional engagement)

Laurel (1991) theorizes that engagement is similar in many ways to the theatrical notion of the "willing suspension of disbelief." She explains:

> *"Engagement involves a kind of complicity. We agree to think and feel in terms of both the content and conventions of a mimetic context. In return, we gain a plethora of new possibilities for action and a kind of emotional guarantee." (pp.115)*

Furthermore,

> *"Engagement is only possible when we can rely on the system to maintain the representational context." (p.115)*

According to Laurel, a dramatic approach to structuring a virtual reality experience has significant benefits in terms of engagement and emotion. It emphasizes the need to delineate and represent human-computer activities as organic wholes with dramatic structural characteristics. And it provides a means whereby people experience activities and involvement naturally and effortlessly.

In Laurel's view, magnitude and closure are two design elements associated with enactment. Magnitude suggests that limiting the duration of an action has aesthetic and cognitive aspects as well as physical ones. Closure suggests that there should be an end point that is satisfying both cognitively and emotionally, providing catharsis. In simulation-based activities, the need for catharsis strongly implies that what goes on be structured as a whole action with a dramatic "shape." For example, "If I am flying a simulated jet fighter, then either I will land successfully or be blown out of the sky, hopefully after some action of a duration that is sufficient to provide pleasure has had a chance to unfold." Catharsis can be accomplished, through a proper understanding of the nature of the whole action and the deployment of dramatic probability. If the end of an activity is the result of a causally related and well-crafted series of events, then the experience of catharsis is the natural result of the moment. Hence, defining the "whole " activity as something that can provide satisfaction and closure when it is achieved is an essential component of engagement. This conforms to the fundamental idea underlying Kearsley & Shneiderman's (1999)'s engagement theory that promote meaningfully engaged learning activities through interaction and worthwhile tasks.

Research in visual perception suggests that if information provided to students is encoded both visually and semantically, then knowledge could be more efficiently constructed, retained and retrieved. Intense and passionate involvement resulting from interacting with activities that are well crafted and causally related leads to catharsis and hence promotes engagement. Other elements such as learning by doing, contextual activities, achieving goals by stages, exploration, testing and reflection, fantasy, enactment, practice and closure provides satisfaction and catharsis, resulting in engagement.

3.3 Motivation

The cognitive orientations discussed so far have not taken into account motivation in learning. The most well-articulated, well-organised and well-managed learning will not have a chance to be effective unless it takes into account all the social and motivational factors within which instruction takes place (Weiner 1990). What motivates an individual to initiate and complete a task? And how can motivation be sustained?

3.3.1 Sources of Motivation

Curiosity

In children and adults alike, curiosity is a strong motivator of learning. One type of curiosity, perceptual arousal, is initially stimulated by novel, complex, or incongruous patterns in the environment (Berlyne 1965b). Not only do learners pay greater attention to these unexpected events, they are also moved to try new ways of perceiving what they are looking at (Gagné & Driscoll 1988). However, curiosity must be sustained in order for it to be a continuing source of motivation. One way of maintaining attention on a perceptual level is to vary the instructional approaches used (Keller 1983, 1987). Another means of sustaining curiosity involves fantasy as it entails providing learners with a meaningful context for learning that is easy to augment with their imaginations (Malone 1981). Finally, a "deeper level of curiosity may be activated by creating a problem situation which can be resolved by knowledge-seeking behaviour" (Keller 1987). Keller called this inquiry arousal, and it is a factor that researchers in CTGV (1992a) contend is brought about by the complexity of the problem in their instructional videos. They intentionally pose very complex and realistic problems for students to solve, and then provide throughout each video numerous clues and information necessary to solve the problems. The result, they say, is enhanced motivation on the part of learners, who experience the complexity of problems that is characteristic of real life. The intrinsic stimulation of curiosity, challenge and fantasy coupled with prolonged engagement in learning tasks is similar to principles adopted in computer games (Malone 1981, Quinn 1997) and virtual worlds (Dede 1992) resulting in disequilibrium. As previously discussed, completion of these tasks lead to feelings of confidence and competence.

Learning Task Relevance

Common sense dictates that students will be more motivated to learn things that are relevant to their interests, but how to make learning environments relevant to students is a complicated affair. How can teachers help learners both to set and attain relevant goals in a subject? How can instruction be designed to meet students' needs for achievements or needs for affiliation? To do that, there is a need to look at literature conducted on goal setting and motive matching.

Actively setting goals can be an important source of motivation (Bandura 1977). When an individual set goals, they determine an external standard against which they will internally evaluate their present level of performance. To the extent that this standard is not met and their goals are not yet achieved, learners will persist in their efforts. Undoubtedly, most people have had the experience of "sticking with it" until a goal set has been achieved. Not all goals, however, will prompt this persistence in learning. In a review of studies on goal setting and task performance, Locke et. al. (1981) identified certain properties of goals that are important to the goal setting process. For example, setting explicit goals is better than setting general goals for motivating persistent behaviour. Moreover, as long as the learner is capable of performing the goal, setting more difficult goals tends to lead to greater persistence and better performance. There are also differences between setting proximal (those that are close at hand and achievable quickly) versus distal (those that set criteria to be met in the distant future) goals (Schunk & Gaa 1981). Not surprisingly, results indicate that setting proximal goals improves self-motivation and performance to a greater extent. This result may be important in problem solving of distal goals when there is a need to break down these goals into more proximal goals. Dweck and her colleagues (Dweck 1986, Dweck & Elliot 1983, Dweck & Leggett 1988, Elliot & Dweck 1988) have conceptualised two types of goals, which influence achievement motivation. Dweck (1986) says that when learners set performance goals, they

> *"seek to gain favourable judgements of their competence or avoid negative judgements in their competence" (pp. 1040).*

When they set learning goals, on the other hand, learners

> *"seek to increase their competence, to understand or master something new" (pp. 1040).*

Dweck's studies have provided evidence that different goals promote different motivational patterns. For instance, faced with a performance goal, students who have little confidence in their abilities display helplessness. They avoid challenge and, given the chance, will quit rather than persist in the task. In the same situation, learners who have high confidence in their abilities will seek a challenge and tend to demonstrate high persistence of the task. Where learning goals are concerned, on the other hand, students' assessments of their present ability is irrelevant. They all display what Dweck & Leggett (1988) called a "mastery-oriented" pattern of motivation. That is, they select challenging tasks, which are believed to benefit learning, and they demonstrate persistence in those tasks. The differences appear to lie in how individuals interpret their failures within the two goal orientations. Performance goals foster the implicit belief that intelligence is fixed. Under this goal orientation, then, learners ask whether their abilities are adequate to the task, and failing is taken to mean the answer is "no". By contrast, learning goals are associated with the belief that intelligence is malleable and can be developed. Under a learning goal orientation, strategies for task mastery are emphasized, and learners ask themselves how their abilities might best be applied and increased to achieve the goal. Failure in this case signals a problem with the current strategy and the necessity to revise that strategy. An obvious result is that learners will expend more effort to learn in this situation than when they believe they do not have the ability to achieve the goal. Hence it is apparent that setting challenging, proximal goals contributes to motivation and can lead to enhanced performance. But this is most likely to occur when the goals are oriented towards learning, as opposed to performance.

The degree to which learning tasks meet particular student needs or align with student values is another aspect of learners' cognition. Keller (1987) suggested that instructors be sensitive to individuals' needs for achievement and for affiliation. Students who have a high need for achievement benefit from setting their own goals and having considerable control over the means of achieving these goals. Students who have a high need for affiliation flourish in non-competitive situations, such as cooperative groups working together toward the achievement of a goal. Keller also concurred with Martin (1987) in recommending the use of appealing methods of teaching to promote continuing motivation. Included in his suggestions are games, cooperative activities, positive role models, personal achievement opportunities and opportunities for leadership.

Self-Efficacy

Another strong source of motivation comes from learners' beliefs about themselves in relation to task difficulty and task outcome. According to Bandura (1977, 1982), self-efficacy involves a belief that one can produce some behaviour, independent of whether one actually can or not. Bandura proposed the concept as a mediator of performance and achievement. That is, learners can be sure that certain activities will produce a particular set of outcomes. These expectations are what Bandura (1977) referred to as outcome expectations. But, if learners harbour serious doubts as to whether they can perform those required activities, they will not put forth the effort. These self-assessments are called efficacy expectations, and according to Bandura, both outcome and efficacy expectations must be met before a person will enact a behaviour that leads to an anticipated outcome. So how do learners acquire efficacy expectations initially? Bandura (1982) suggested four possible sources by which people can gain information to influence their self-efficacy. These are:

- *Performance accomplishments*, referring to learner's own previous success at a task. If a learner had a previous success in doing a similar task, he or she has an increased expectation of being successful.
- *Vicarious experience,* the learner's observation of a role model attaining success at a task.
- *Verbal persuasion,* others persuading a learner that he or she is capable of succeeding at a particular task.
- *Physiological states,* the learners' "gut feeling" convinces them of probable success or failure.

Outcome expectations relate to both the learner's understanding of what activities are required to reach a learning goal and what consequences reaching the goal will assure. In a sense, this parallels the distinction between learning and performance made by Dweck (1986) earlier. On the one hand, students acquire an expectation of what is to be learned by setting goals or being told by the teacher what the goals are. Students with a learning (as opposed to performance) orientation will then employ whatever learning and study strategies they believe will enable them to be successful in attaining the goals. On the other hand, students also form an expectation about the consequences of goal achievement, and these consequences must have value for them to initiate and persist in a learning task. The extent to which learners value these consequences, then, affects their motivation to succeed in the learning task.

3.3.2 Consequences, Context and Continuing Motivation

What happens as a result of past learning determines to a large extent whether students will engage in new learning at some time in the future. At least two factors are important in considering the continuing motivation to learn. These are (1) whether students' expectations about learning and its consequences have been met and (2) to what students attribute their failures and successes in learning.

When learners succeed at a task, two expectations have typically been met. There is the satisfaction of the outcome expectation. There is also, however, the satisfaction of efficacy expectations. A source of information about self-efficacy is one's previous success at the task. Thus, once success is attained, self-efficacy is increased. Keller (1983,1987) says that one of the most rewarding (and subsequently, motivating) results of learning is to use the newly acquired skills or knowledge. He referred to this as the natural consequences of learning. Natural consequences occur most often when students see the relevance in what they are learning and have the opportunity to apply newly acquired information. In the event that natural consequences are less likely to occur, outcome expectations may still be satisfied through what Keller (1983, 1987) called positive consequences. These are extrinsic reinforcements such as awards, positive comments, and other rewards. There is a view, however, that providing rewards only for participating in an activity may lead to decreased interest in that activity (Bates 1979). This is especially true when the activity is itself entertaining or stimulating. So, for example, it would probably be unwise to reward learners for engaging in some task that already interests them. However, Calder & Staw (1975) believed that positive consequences can be especially useful when learning tasks are inherently boring or their relevance is not perceived by the learner. Keller (1987) also pointed out that

"even when people are intrinsically motivated to learn the material, there are likely to be benefits from extrinsic forms of recognition." (Pp. 6).

Weiner (1979) also postulates that students' attributions to their success or failures about learning and performance constitute an important influence on continuing motivation to learn. Internal causes of success or failure are those factors within the person, such as ability, effort and mood. External causes are those outside the learner, such as task difficulty, the attitude of the teacher, help from other people and so on. Weiner also points out the two factors affecting internal and external attributes: stability and controllability. The stability factor refers to how changeable a factor is over time. Controllability refers to the degree to which the individuals have control over the causes of success or failure. It is obvious, then, that ability for example, is internal, relatively stable and controllable only over the long term (high achievement in a subject leads to potential for further achievement in the same subject). Help from another student, on the other hand, is external, unstable and uncontrollable by the learner. If a learner attributes his or her failure to low ability, then this would lead to a vicious cycle where they are not motivated to apply themselves on the next task (Graham & Barker 1990). If, on the other hand, learners attribute their failures to unstable or controllable causes, they are more likely to believe that they will succeed in the future. Graham & Barker also found that unsolicited well-intentioned help to less able students resulted in these students inferring that they have low ability. Hence, regarding the effect of attributions on continuing motivation, helping learners to attribute their successes and failures to effort and effective (or ineffective) learning strategies is a procedure likely to facilitate motivation. For learners with a history of failures, teachers need to be especially alert to cues that might further erode individuals' opinions of their abilities.

In summary then, continuing motivation to learn is facilitated through the satisfaction of expectancies in the current learning episode. When learners succeed at a learning goal, their self-efficacy increases and they experience the natural consequences of learning success. Where natural consequences are less likely to occur, positive consequences can serve in some situations to satisfy an outcome expectation. Motivation appears to be enhanced when learners' expectancies are satisfied, when they attribute their successes to their own efforts and effective learning strategies.

3.4 Discussion & Findings

With regards to learning in VE, discussion of literature reviewed in this chapter can be divided in 3 sections. Learning theories, visual perception and engagement and motivation.

Learning Theories

Behaviourism and cognitivism both support the practice of analysing a task and breaking it down into manageable chunks, establishing objectives, and measuring performance based on these objectives. Constructivism, on the other hand, promotes a more open-ended learning experience where the methods and results of learning are not easily measured and may not be the same for each learner. While behaviourism and constructivism are very different theoretical perspectives, cognitivism shares some similarities with constructivism. An example of their compatibility is the fact that they share the analogy of comparing the process of the mind to that of a computer. Consider the following statement by Perkins (1992a):

> "... *information processing models have spawned the computer model of the mind as an information processor. Constructivism has added that this information processor must be seen as not just shuffling*

data, but wielding it flexibly during learning – making hypotheses, testing tentative interpretations, and so on." (Pp. 51)

The objective side of cognitivism supported the use of models to be used in the systems approach of instructional design. Constructivism is not compatible with the present systems approach to instructional design, as Jonassen (1994) pointed out. The conundrum that constructivism posed is that if each individual is responsible for knowledge construction, how would a common set of outcomes for learning be ensured by instructional designers? He advocated that purposeful knowledge construction might be facilitated by learning environments following seven principles (previously discussed in section 2.2.3) which include: Providing multiple representation of reality, presenting authentic tasks, providing real-world, case-based learning environments, fostering reflective practice, enabling context and content dependent knowledge construction, supporting collaborative construction of knowledge through social negotiation and lastly encouraging knowledge construction.

Jonassen pointed out that the difference between constructivist and behaviourist instructional design is that objective design has a predetermined outcome and intervenes in the learning process to map a pre-determined concept of reality into the learner's mind, while constructivism maintains that because learning outcomes are not always predictable, instruction should foster, not control, learning.

There is a need to recognise that circumstances surrounding the learning situation should be used to decide which approach to learning is most appropriate. It is necessary to realize that some learning problems require highly prescriptive solutions, whereas others are more suited to learner control of the environment. It is important to recognise that there is no one perfect solution. This finding also parallels the conclusion of Schwier (1995) in his work on comparing behaviourism, cognitivism and constructivism. Hence, one should not advocate one single learning theory, but the instructional strategy and content addressed depend on the level of the learners. It was felt that the instructional approach used for novice learners might not efficiently stimulate a learner who is familiar with the content. For example, a behavioural approach can effectively facilitate mastery of the content of a profession (knowing what); cognitive strategies are useful in teaching problem solving tactics where defined facts and rules are applied in unfamiliar situations (knowing how); and constructivist strategies are especially suited to dealing with ill-defined problems through reflection-in-action. Also, the strategies promoted by different learning theories seem to overlap (the same strategy for a different reason) and learning theory strategies are concentrated along different points in a continuum depending on the level of cognitive processing required. Findings by Ertmer & Newby (1993) showed similar conclusions in that they found theoretical strategies can complement the learner's level of task knowledge, allowing the instructional designer to draw from a large number of strategies to meet a variety of learning needs. Figure 3-1 shows a figure from their article comparing behavioural, cognitive and constructivist viewpoints based on a learner's level of task knowledge and cognitive processing required in a task.

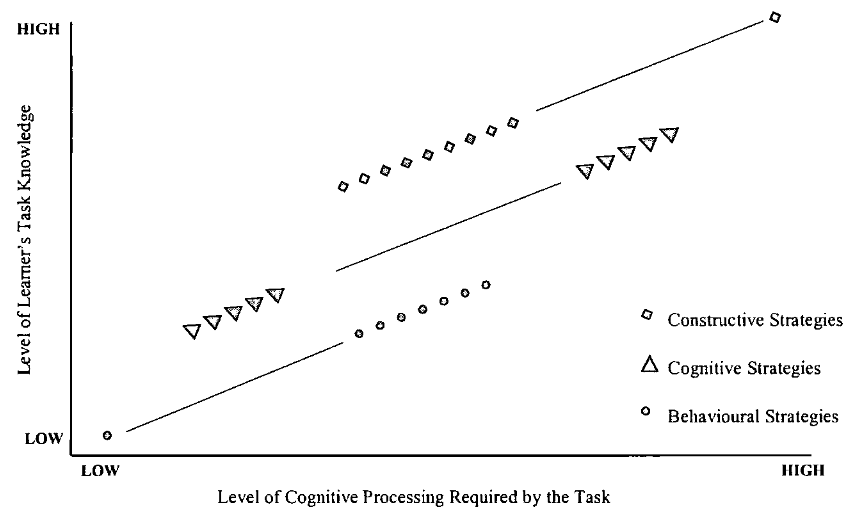

Figure 3-1: Comparison of behavioural, cognitive and constructivist viewpoints based on learner's level of task knowledge and level of cognitive processing required by the task (Ertmer & Newby 1993)

In the learning theories section, the level of prior knowledge of a learner in a particular domain is shown to affect the kind of instructional strategy used for him or her. It is apparent that prior knowledge is paramount to all aspects of cognitive psychology as confirmed by various researchers (di Vesta 1987, Mayer 1979, Tobias 1987). Its significance is probably best summarized by Ausubel (1978): "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly". Hence, prior knowledge also provides the potential for supporting schema related to forthcoming instruction, improved capacity for comprehensive monitoring and meaningful learning. When supporting knowledge exists, based on the user's prior knowledge, learners gain the capacity to compare and contrast to-be-learned content within existing knowledge, providing uniquely relevant elaboration unavailable to learners with limited prior knowledge. Consequently, lesson knowledge generally will be encoded more meaningfully and retrieved more successfully by learners with high versus low knowledge.

The constructivist perspectives places heavy demands on the educational setting and information-processing technology is seen as a viable option in building kinds of more intimate and supporting learning environment.

Visual Perception & Engagement

Visual perception is based on prior knowledge and experiences and solving problems requires seeing problems in a "new" light. Evidences indicated that practice on many kinds of problems could make learners aware of the role of the context in problem solution, exposing the learner to consider alternates. This is linked closely to the constructivist approach of learning where cognitive conflict causes the learner to refine his or her mental structures, including building new constructions through assimilation and accommodation. Practice also allows the generation of multiple perspectives useful for learning in the constructivist environment. Dual coding theory proposes that information encoded in both visual and semantic forms enhances retention, retrieval and transfer, supporting findings in chapter 2 where visualisation together with some form of semantic cueing enhances learning.

Literature on engagement showed that intense and passionate involvement resulting from interacting with activities that are well crafted and causally related leads to catharsis and hence promotes engagement. Elements of fun and fantasy were shown to aid engagement and computer games employing enactment and visualisation allow "seeing" causal relationships between individual actions and whole systems. Learning by doing, in contextually congruent activities, allowing exploration and experimentisation were said to provide satisfaction and catharsis, resulting in engagement. Many of the features shown are inherent in virtual environments.

Motivation

Two issues were of concern. What motivates an individual and how to sustain the motivation level throughout the learning process?

Literature showed that curiosity, learning task relevance and belief in self-efficacy were factors considered in motivating an individual. Perceptual arousal, stimulated by novel patterns in the environment is a means to initiate curiosity and inquiry arousal. A "deeper level of curiosity" can be initiated by creating a problem situation which can be resolved by knowledge seeking behaviour. Actively setting goals was shown to be an important source of motivation. Distal goals can be broken down into more proximal goals. Setting challenging, proximal goals contributes to motivation but this is most likely to occur only when the goals are oriented towards learning, as opposed to performance goals. Learners pursuing learning goals frequently exhibit a "mastery-oriented" pattern of motivation. Students also form expectations about the consequences of goal achievement, and these consequences need to have value for them to initiate and persist in a learning task. The extent to which learners value these consequences, then, affects their motivation to succeed in the task. These are known as outcome expectations. Efficacy expectations are learners' own assessment as to whether they can perform the required activities. Both outcome and efficacy expectations have to be met before a learner will exhibit behaviour leading to motivation behaviour.

Two factors were considered in relation to the continuing motivation to learn. These are whether the student's expectations about learning and its consequences have been met and what students attribute their failures and successes in learning. Continuing motivation to learn is facilitated through the satisfaction of expectancies in the current learning episode. When learners succeed at a learning goal, their self-efficacy increases and they experience the natural consequences of learning success. Where natural consequences are less likely to occur, positive consequences can serve in some situations to satisfy an outcome expectation. Motivation appears to be enhanced when learners' expectancies are satisfied, and when they attribute their successes to their own efforts and effective learning strategies.

Many of the findings in motivation can be incorporated in designing a VE. For example, the idea of perceptual and inquiry arousal, the concept of distal and proximal goals, the setting of learning versus performance goals and the satisfaction of efficacy and outcome expectations.

PART III

RESEARCH

4. METHODOLOGY

4.1 Introduction

Chapters 2 and 3 identified the problems and research questions dealing with learning in virtual environments. In chapter 2, literature revealed that in many cases, research did not take into account pre-conditions for implementing VEs in learning. These are:

- Justification of the need for using VR in learning
- Ensure elimination of ceiling and maturation effects
- Ensuring a certain complexity level of the concept to be introduced
- Ensuring congruence of the VE to the topic discussed
- Providing semantic cueing/support
- Understanding the level of prior knowledge of the students

This can lead to inaccurate interpretation of the empirical results. A number of factors were also attributed to successful learning in VEs, such as inclusion, engagement, providing multiple viewpoints, increased motivation and self motivation, direct interaction, feedback, practice and so on, which needed confirmation.

Chapter 3 clarified a number of issues regarding learning models discussed in chapter 2. The underpinnings for using the constructivist model in learning, the suggestion that the circumstances surrounding the learning situation needed to be recognised in order to select the learning strategy, the level of prior knowledge of the students, the theoretical awareness of visual perception, encoding, memory and retrieval, and the use of motivational literature in further understanding learning.

By taking into account the findings above, an empirical study was conducted to answer the following basic questions:

1. Did VR technology help improve students' learning processes when compared to traditional classroom methods? How did it help?
2. Which aspects of using VR assisted the learning process?
3. Were students motivated by the VR experience? How were they motivated?
4. Which aspects of using VR motivated the students?
5. Were students still able to collaborate while learning through a VR environment?
6. Did students prefer VR as a learning tool to traditional method?

The course subject chosen for this study was Computer Integrated Manufacturing (CIM). In this particular course subject, a virtual environment prototype was developed in 1998 (Tan & Ward 1998[1]) to augment CIM teaching and has been used since in the Mechatronics diploma course (a diploma combining the essence of mechanical, electronics and computer discipline) in the School of Engineering, Temasek Polytechnic, Singapore. Unfortunately, data on the usefulness of the tool was not collected. This study involved using this particular VRCIM (Virtual Reality Computer Integrated Manufacturing) environment to augment the teaching of the first five chapters of the course and to determine its effectiveness by examining points raised in the research questions. In this chapter, the identified research questions are distilled into an empirical research experiment. The chapter will describe how the research questions

[1] Tan & Ward 1998 can be accessed from http://cvd.tp.edu.sg/publications/resonate/vrcim.pdf

led to the design of the study, the design of experiment, the instruments used, the procedures used in the study, the study subjects and the method of analysis.

CIM is a complex subject that promulgates a fundamental strategy of integrating manufacturing facilities and systems in an enterprise through computers and their peripherals (Lin 1997). Tan & Ward (1998) felt that incorporating VR into the training is useful in that it is a subject requiring experimentation to fully understand the concepts. Student are constrained when they handle physical machines due to the danger they might pose to themselves as well as other people. Expensive equipment may be damaged. In the VE, students can safely trial out their ideas. Furthermore, because the system mimics a real factory, it allows the students to interact with the environment. Extensive documentation and help screens also supported the system. The students (see details in section 4.8) involved in the experiment were those that had passed a common second year examination. As such, they had a proper foundation for handling the subject. Section 4.9 details the experimental procedure where students were divided into 2 separate groups (Group I, the VR augmented group and Group II, the traditional group) and given separate treatment. The same instructor administered both treatments. Group I students used the VR software in addition to their lecture material while Group II students relied on the traditional lecture and tutorial arrangement. Both groups had the same number of training hours.

4.2 Methodology

In designing the methodology, guidance was taken from approaches used by education researchers indicated in Hammersley (1993) and Cohen, Manion & Morrison (2000). Amongst other issues, it was noted that there has been a shift from the dominance of quantitative approaches to the increasing use of qualitative methods. There is also the classical approach. Huck, Cormier & Bounds (1974) described this as a four-phased approach. A) Identify the participants, B) Identify the research design. C) Identify the material (test instruments) used, and D), Identify the procedures. More elaborate methods have been described in Kerlinger (1970) and Hitchcock & Hughes (1995). In addition, a humanistic approach (Harré & Secord, 1972 and Beck, 1979) allowed more in depth understanding of issues involved. Punch (1998) suggested a method-connection approach, where the research questions are analysed to determine the method to be used. The need for an experimental paradigm to assess the progress of two groups, as well as for exploratory methodologies to investigate aspects of students' experience when learning under two separate conditions suggests a combination of methodology. The research questions also required that there be a quantitative element as well as qualitative element. The classical approach aimed to ensure that the experiment procedures and data were properly collected and analysed; the qualitative method aimed to ensure depth in issues not covered by the classical approach and the method-connection approach was used to determine a particular approach suitable for a particular question.

For example, the research question, "Did VR technology help improve students' learning processes when compared to traditional classroom methods?" required both quantitative and qualitative evidence. A "before and after" test between two groups of initially similar students put through two different sets of learning paradigm would not provide sufficient information, as data on how students learn would not have been captured. To support the findings, evidence also had to be found about the learning process. The presence and significance of factors such as:

- Goal setting
- Breaking problems into sub-goals (Planning)
- Recognition of tasks to be performed
- Trial & error (Experimentation)
- Use of feedback
- Ability to develop solutions
- Independent thinking
- Learning Strategy

had to be taken into account. Hence instruments would need to be designed to collect the required information. The second question, "Which aspects of using VR assisted the learning process?" extended the first question by seeking out the aspects of VR, which might make learning effective. The third question, "Were students motivated by the VR experience?" explored an intrinsic factor in learning, the motivational factor, leading to the fourth question, "Which aspects of using VR motivated the student?" The fifth question, "Were students still able to collaborate while learning through a VR environment?" sought to find out if there was evidence of group or collaborative learning. The last question sought the learners' opinion on the learning process to find out if diploma level engineering students prefer using a visualisation tool to traditional classroom learning.

From the research questions, it can be seen that two groups of students would have to be selected as subjects in this study. One group would have to be subjected to using VR as a learning tool while the other would need to learn using the traditional method of classroom learning. It would be necessary to show that the two groups of students were drawn from the same education pool and level and that they were not significantly different in terms of their knowledge. It was felt that a fair measure would be to use the previous examination results of these students as a gauge. If their results were not significantly different, it would be fair to assume that they had similar prior knowledge.

Similarly, the design of experiment would need to use both qualitative and quantitative tools in seeking answers to the research questions. For example, learning is not only concerned with the end result but also with the learning process itself. Although the end result would be one way of quantifying how much the student has learnt of the subject, it would be useful to find out how they learn and what thinking process has gone into the learning. Hence, one of the instruments would need to measure the end result after the experimental "treatment". It was decided that a "past-year" term-test script covering the topics concerned would be used, as this was the current form whereby students were judged on their performance. A combination of a survey questionnaire and interviews would be used to gauge the students' learning process and their preference. The survey questionnaire would capture information relating to research questions 1 to 6, including some qualitative questions on students' learning processes and strategies used. An interview would be used to complement the questionnaire by expanding, unfolding and clarifying what the students had written. This would be implemented by interviewing selected students. The criteria of selection would be to follow up in greater depth:

a) responses which seemed inconsistent and contradictory,

b) questions with few response but ones which seemed particularly interesting and

c) students who provided ambiguous or unclear statements.

This meant that there would be two phases of data collection. The first phase of data collection would be performed immediately after the "treatment". The written term-test and survey questionnaire would be in this phase. After an initial phase of analysing the questionnaire to identify candidates, interviews would be carried out as the second phase of data collection. Data from the three instruments (term-test paper, questionnaire and interview) would then be organised and inferences would be drawn.

4.3 Research Hypothesis

Polytechnic level students studying Computer Integrated Manufacturing (CIM) using virtual reality as an augmentation tool (Group I) will demonstrate significantly better content assimilation and retention, develop more extensive mental models and experience greater learning motivation as measured by quantitative results from a written assessment, an analysis of students' replies to a survey questionnaire, and qualitative analyses from interviews when compared to those students using traditional learning strategies (Group II).

4.4 Design of Experiment

This section will be used to discuss the design of the experiment and tools used in the study. Section 4.2 showed the research questions and how they were related to the methods that would be used here. A two-group, two-treatment analysis was designed, as the main objective was to study and compare students who use VR augmentation as part of their learning with students who learn by traditional means. Hence, students in the study were divided into two groups, Group I and Group II. Group I students undertook learning with the use of VR augmentation while Group II students were taught without. To ensure that the two groups of students had similar initial knowledge, a statistical study was performed based on their examination results. This is indicated in section 4.8. It should be noted that both groups of students had introductory knowledge of VR, as it was compulsory for all students as part of their year one curriculum to visit the virtual reality competency unit, a research centre located in the polytechnic premises. During the 1-hour visit, the students were introduced to the technology as well as to the various applications developed by the unit.

A total period of 15 hours was set aside for each group. Each group used 3 hours per day to learn the course content (See table 4-1). The course modules covered were Chapters 1 through 5 of the CIM syllabus. Group I spent 1.5 hours on lecture/tutorial and another 1.5 hours on the VR system each day, with a break of .5 hour in between. Group II spent 2 hours on lectures and 1 on tutorial, with a .25 hour break after every hour. Both groups were taught by the same instructor. Lessons were conducted for 20 students at the same time in each group. Detail of the experimental procedure for conducting the experiment is found in section 4.9.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
GROUP I VR AUGMENTA- TION (hrs)	Lecture/ Tutorial 1.5 (.5 break) Lab 1.5	Lecture/ Tutorial 1.5 (.5 break) Lab 1.5	Lecture/ Tutorial 1.5 (.5 break) Lab 1.5	Lecture/ Tutorial 1.5 (.5 break) Lab 1.5	Lecture/ Tutorial 1.5 (.5 break) Lab 1.5 Survey	Test
GROUP II TRADITIONAL GROUP NO VR AUGMENTA- TION (hrs)	Lecture 1 (.25 break) 1 (.25 break) Tutorial 1	Lecture 1 (.25 break) 1 (.25 break) Tutorial 1	Lecture 1 (.25 break) 1 (.25 break) Tutorial 1	Lecture 1 (.25 break) 1 (.25 break) Tutorial 1	Lecture 1 (.25 break) 1 (.25 break) Tutorial 1 Survey	Test

Table 4-1: Time distribution in training (hours)

After the treatment, Group I & II students were required to take a formal written test (drawn from a past-year term test paper). The detail of the design of the written test is shown in section 4.5. In addition, both groups of students took part in a survey to determine their perception, and attitudes toward tasks, interactions and processes. Two different sets of survey questionnaires were designed, one for Group I; and another for

Group II students. Details of the design of the survey questionnaire are found in section 4.6. In this experiment, the interview sessions were to be used to complement the questionnaire and to expand on, and clarify what students had written. The aim would be to follow up in greater depth:

a) responses which seemed inconsistent and contradictory,

b) questions with few response but ones which seemed particularly interesting and

c) students who provided ambiguous or unclear statements.

Hence, there would not be a need to interview all the students. The interviews were only conducted after an initial analysis of the questionnaire where interview questions were identified and interviews with students scheduled. This took two weeks. Students with interesting feedback were then interviewed. The interview was the third instrument. Detail of design is shown in section 4.7.

In summary, three instruments were designed to assess the students' learning. The first was a survey conducted on the last day of the taught sessions for both groups of students. The second was a 1-hour test conducted on the final day (see table 4-1) and the third, the interview. The constructivist-learning paradigm was paired with the virtual environment learning process as part of the learning paradigm where they were allowed to arrive at their own solution through the virtual environment.

Scores from the formal test were used in a quantitative analysis to analyse whether the hypothesis was supported. Results from the survey and interview were used to find factors influencing learning in the virtual environment.

4.5 Design of Assessment of Students' Learning

The term-test paper was a one-hour paper. The paper had two sections. Section A contained 3 short questions (Questions 1 to 3), each worth 20 marks and section B contained 1 long question (Question 4) worth 40 marks. The students were required to answer all questions. The term-test paper can be found in Appendix A. The questions were based on the chapter topics shown in Table 4-2.

Day	Chapter	Topic	Covered in Tutorial
1	1 and 2	Introduction to Manufacturing Systems/CIM Concepts & Models	1
2	3	Group Technology & Cellular Manufacturing	2
3	4	Computer Aided Planning Systems (1)	3
4	4	Computer Aided Planning Systems (2)	4
5	5	Flexible Manufacturing Systems	5

Table 4-2: Topics Covered

The distribution of marks for the test is shown below in table 4-3.

Question No.	Taken From Chapter	Test Section	Learning Assessment
1 (20 marks compulsory)	3	A	Memory work and application
2 (20 marks compulsory)	4	A	Memory work and ability to differentiate
3 (20 marks compulsory)	1, 2, 5	A	Memory work and application of formulae
4 (40 marks compulsory)	4	B	Problem solving skills & calculations

Table 4-3: Question Distribution

The questions were designed to be completed within an hour. Each section A question was expected to be completed in 12 minutes, totalling 36 minutes. The section B question was designed to be completed in 24 minutes. It can be observed that 2 questions, question 2 from section A and question 4 from section B, were taken from chapter 4. This was not surprising as the chapter was covered in two sessions.

The scoring of the test was based on the marking scheme provided for this particular test. As this was a past-year term paper, the marking scheme was obtained from the polytechnic's examination archive and marking was carried out according to the schema. The total score on this quantitative test instrument was used to test the hypothesis that students' learning using VR augmentation would demonstrate significantly better content assimilation and retention than students learning using ordinary methods. An analysis of the overall result as well as on each question of the paper was carried out. This would also provide understanding of how well students from both Group I and II performed in the various assessment types.

To ensure marking reliability, during the test, the students' seating arrangements were randomised and the test scripts collected in that manner and marked. This made sure that marking was done blind (i.e. with the marker unaware of whose paper he was marking).

4.6 Design of Questionnaire

The survey questionnaires were used to collect information regarding student's models of learning and cognition in areas such as:

- Planning
- Goal Setting/Setting Sub-goals
- Improved Understanding of problem and solution
- Evolution of solution from trials and feedbacks
- Reflection on problem solving
- Abstraction to other application
- Active involvement in working out a solution
- Divergent thinking
- Convergent thinking
- Learning Method Preference
- Self learning/Independence
- Assimilation
- Collaboration

- Perceived ease of learning
- Enjoyment of learning
- Problem Solving

An introductory cover page was designed to explain the purpose of the experiment to the student as well as attach instructions for the survey. The questionnaire was designed so that it followed a broad scheme of (1) introduction, (2) warm-up questions and (3) body of study using guidelines from Burns (2000). This was to lead the respondent into the questionnaire, thereby making it more difficult to withdraw. Two different sets of survey questionnaires were administered, one for the students using VR/VE in Group I, and another for the students in the traditional learning group, Group II. The survey questionnaires were developed to provide information on how the students learned in the two different methods, mental models developed during the learning process and their attitudes and preferences toward using VE as a learning aid. Appendix B shows the two sets of survey questionnaires, one for the VR/VE group and another for the traditional group.

There were altogether 38 questions in the questionnaire; questions 1 to 33 were questions based on a Likert Scale. The question categories were grouped as shown in table 4-4.

There were nine complementary questions in the multiple-choice questions, Questions 14, 16, 18, 22, 23, 28, 29, 32 and 33, which sought to throw further light on the students' preference and perceptions in working with VR/VE. In addition, there were 3 "negative" questions, 19, 21 and 30. These were put in to break the monotony of the answering pattern. According to Berlyne (1965a), "attention would be aroused by things that are novel or uncertain" and to stimulate and sustain attention, elements of uncertainty were introduced into the survey.

Question 34 to 36 were open ended questions and were used to capture the following information.

For Group I, Question 34 sought the students' views on learning a task through a VR environment. This served to: (i) capture any missing information from question 1 through 33 on the student's learning; (ii) reinforce information provided. For Group II, the question sought to discover similar views from the students in the traditional group.

Question 35/36 sought to discover the students' best liked and worst liked event in learning from VR/VE and the traditional environment. This was to help identify motivating factors.

Question 37 was designed to identify features in the system students felt were most important in their learning process in VR/VE. Hence, a table of various aspects of VR/VE was provided and the students were expected to rank the features. A similar question was provided to the traditional group to find out features in the traditional system in order of importance.

Question 38 was designed to discover how students worked out their solution in the form of concept maps. This data could be collected in graphical form. Careful analysis of this question gave valuable insights into how problem definition and problem solving was done. Details of analysis can be found in chapters 5 and 6.

CATEGORIES OF LEARNING ACTIVITIES

Q	Plan	Goal Setting	Sub-Goals	Improved Understanding	Trial & Feedback	Reflection	Abstraction	Active Involvement	Divergent Thinking	Convergent Thinking	Learning Method Preference	Safety	Self Learn	Assimilation	Collaboration	Perceived Ease of Learning	Enjoyment	Problem Solving
1		✓																
2	✓		✓															
3	✓																	
4				✓														
5				✓														
6					✓													
7					✓													
8						✓												
9	✓			✓						✓								
10	✓																	✓
11							✓											
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27															✓			✓
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29																✓		
30																✓		
31											✓							
32														✓				
33																✓		

Table 4-4: Categories of Learning Activities

4.7 Design of Interview Schedule

In addition to the above instruments, selected students were interviewed after an initial analysis of the survey questionnaire. These interviews were recorded and transcripts of each interview were produced.

The main aim of the interview sessions was to provide a deeper understanding of the use of VR in augmenting the learning process by probing deeper into the students' comments in the survey questionnaire. Students, whose responses were found to be ambiguous or interesting, were probed further for explanations. Data collected in the survey questionnaire, which showed disproportionate (either too big or too small) percentages of occurrences or had anomalies such as contradictions were identified and students in these groups were interviewed individually to further understand their responses. The interviews were scheduled two weeks after the written test, giving one week for analysis of the survey questionnaire.

A common format was produced, after the analysis. Table 4-5 shows a sample of how questions in the interview were formulated after analysis of the survey questionnaire. The column under "Issues to Clarify" identified questions that need more in-depth study. These questions were brought up during the analysis or from the students' questionnaire. Statements that had too many or too few responses, or that were ambiguous or interesting were selected. The other columns indicate questions to be put to the students in Groups I and II.

A schedule for interviews was set up. Eight students were identified (4 from each group) for the interview sessions. Each interview session lasted 0.5 hour. Details of the interview questions are found in chapter 5.

The transcripts from the interviews were then analysed by determining the frequencies for the major variables occurring in the students' replies.

Issues to Clarify	Group I Question	Group II Question
Independent Learning In question 20, Group I students indicated that they were able to solve problems with practically no help at the end (75%). Group II students only indicated 25%. What was the reason for the disparity?	In question 20, you indicated that you were able to solve problems with practically no help at the end. Why was this so?	In question 20, you indicated that you were not able to solve problems without help at the end. Why was this so?
Assimilation In questions 22, 23 and 32, Group I students indicated that they were able to assimilate more information faster. Why was this so? It was also strange the Group II students indicated in Question 32 that they also thought that they could have learnt more from a VE system (60%).	In questions 22, 23 and 32, you indicated that you were able to assimilate more information faster. What made you say that you were able to learn more and also at a faster rate using the VE?	What made you indicate in question 32 that you would be able to learn more from a VE?

Table 4-5: Sample of question formulation in the Interview after initial analysis.

4.8 Subjects

Subjects in this study were 40 polytechnic students attending the Mechatronics Engineering course in Temasek Polytechnic. There were 20 students in Group 1 and 20 students in Group II. The samples of students were drawn from the same pool that is, students who passed the common year 2 examinations and had made a decision to choose the CIM elective for their final year. Table 4-6 shows the results of a t-test analysis of the year 2 examination marks between Group I and II students. A box-plot of Group I and II students' average examination marks is shown in Figure 4-1. Appendix C contains details of the student examination marks and analysis.

	Mean ($\bar{x}$)	Median	Std. Dev. (σ)	Variance (σ^2)	Levene's Test ($p < 0.05$)	t-test (df = 38, $p < 0.05$)
Group I (n=20)	72.465	71.750	5.306	28.153	F = 0.198 (p=0.659) Not Significant	t = 1.932 (p=0.061) Not Significant
Group II (n=20)	68.575	68.650	7.277	52.955		

Table 4-6: Analysis of 2nd year examination results from both Group I and Group II

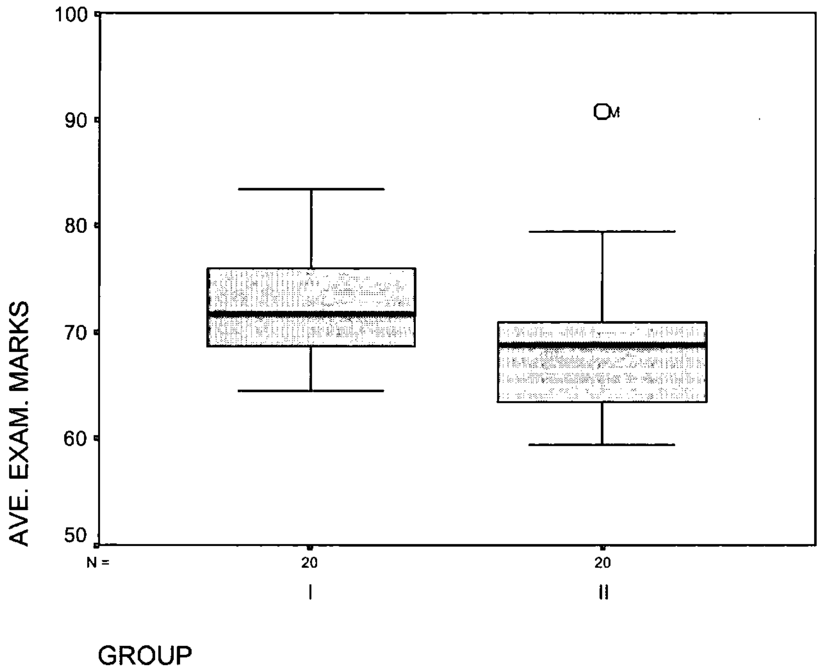


Figure 4-1: Box plot of 2nd year examination results from both Group I and Group II

Using a null hypothesis that there was no difference in the students' average examination results in their year two examinations, an independent 2-tailed t-test was performed. A 0.05 level-of-significance was used in the test. The Critical Value table in Fitz-Gibbon & Morris

(1987), yielded a critical t-value (t_c) of 2.024 at p=0.05, 2 tail test, with a degree of freedom of 38. Hence, the mean examination results of Group I students ($\bar{x}$ = 72.465, σ = 5.306) is not statistically significantly different (t = 1.932, df = 38, two tailed p = 0.061) from that of Group II students ($\bar{x}$ = 68.575, σ = 7.277).

The t-test assumes that the population variances for the two groups are equal. This was verified using Levene's test. The result obtained (F = 0.198, p = 0.659) showed that the variances were not significantly different and hence the population variances of Group I and Group II were not significantly different. Effect size (ES) calculations yielded a value of d = 0.6 which is slightly above half a standard deviation. Green, Salkind & Akey (2000) described this as a "medium" effect. Effect size reflects how large the effect of an independent variable was, that is, the degree to which the phenomenon is present in the population (Burns 2000). Hence, the extent to which the two populations do not overlap is the extent to which the experimental manipulation has an effect of separating the two populations: The larger the difference between the two population means, the greater the effect size, the smaller the variance within the populations, the greater the effect size. Cohen (1988, 1992) explained that a large ES value (indicated as 0.8 and above) would result in a higher probability of making a correct rejection of the null hypothesis when it is false.

Hence, the assumption that Group I and Group II students had similar initial knowledge before they embark on the experiment may be accepted as valid.

The student sample chosen for this experiment were from the students (age between 18 to 20) who had completed the second year of the Diploma in Mechatronics Engineering in Temasek Engineering School. These students had chosen to specialise in CIM as an elective subject in their 3rd year. CIM is a third year subject that requires students to understand how machines work together in a manufacturing scenario to produce goods in an optimum time.

4.9 Experiment Procedure

The study was conducted on site at Temasek Engineering School, Temasek Polytechnic. The first half of the experiment, which included conducting the experiment, the survey and the test lasted six days. The second portion of the study, which included the analysis took a further 7 days, and the interview session itself was completed within a day. The analysis was carried out to identify further questions about the experiment that were used in conducting the interview sessions (see section 4.7). The first half of the experiment was conducted between 10 and 15 December 2001, while the analysis took place between 17 and 23 December 2001. The interview sessions was conducted on 28 December 2001.

Prior to the experiment, students from both Group I and II attended a one-hour briefing session on 7 December 2001. These students volunteers were some of the students that chose to undertake the CIM elective in the new semester. The motivation was that they would be learning part of the subject ahead of their classmates when the new semester started in January 2002. Whichever group the students were in, they would benefit from the lessons and test conducted during the experiment. The purpose was to give the students a background to the experiment, explain what was required of them and answer all their queries. Another objective was also to ensure that both groups would not feel disadvantaged during the experiment. In the briefing, the following was discussed:

i. Background to the experiment
ii. Procedures of the experiment
iii. Why it was necessary to have two groups of students
iv. Course schedules and course material (hand-outs provided)
v. Questions and Answers Session

Table 4-1 shows a summary of the time distribution in the study. There were 1-hour blocks for Group II and 1.5-hour blocks for Group I. The students in Group II took the morning session, from 9am – 12.30pm with breaks of .25 hour (15 minutes) after the first and second hour. Group I students took the afternoon session between 1.30pm to 5pm with a single break of .5 hour (30 minutes) after 1.5 hours. The same instructor conducted the lessons for both groups of students. Lessons were conducted for 20 students at the same time in each group, using course notes provided. The topics taught are shown in table 4-2.

In Group I, lessons were conducted in the computer laboratory. The lesson plan for this group included a brief lecture on the day's topic by the instructor (25 minutes) using power point slides and web media with group discussion (20 minutes), making up a total of 45 minutes. In the group discussion, the students were encouraged to develop an understanding of the concepts discussed in the lecture, the material provided, other material that they sourced from the Internet through the computers in the laboratory and also their experience in the virtual environment. Students were encouraged to discuss problems with their peers or the instructor. After that, students worked on tutorial questions for the next 45 minutes. After a break of .5 hours, Group I students spent the next 1.5 hours working on problems in the virtual environment. The students were put on the computer to allow them to explore the VE know as Virtual Reality CIM (VRCIM) system. During the first lesson, they were given a brief demonstration of system operations and procedures for operating the various machines in the virtual environment. In addition, they were given a task to fulfil, that is, to utilise the VE to produce 2 batches of dissimilar products in the shortest possible production time. The challenge was to programme the individual machine steps and finally the sequencing of machine cells as well as the manipulation of the production plan and schedule to achieve this. The students were to work on this problem for the rest of the time assigned for learning in VE. Manuals and guidebooks on the system were also provided. Because the system mimicked a factory environment, the student could choose to start from any two points in the system. The student could choose to start from the VR environment where his or her role would be a machine programmer or from the Host Controller Module where the role would be that of a production planner. As a machine programmer, the student had to learn to program the machines as well as the cell controllers to produce the specified products. As a production planner, the student would have to plan the processes and schedules associated with the factory environment. The system has been described in Tan and Ward (1998). Screen captures of the environment is shown in Appendix D.

Group II students' lessons were conducted in a classroom. Again, the schedule was according to the plan shown in table 4-2. The lesson plan for Group II each day included, 2 lectures on the topic (1 hour each, with a .25 hour break after every hour) and a tutorial session (1 hour). Lectures involved the instructor using power point presentations and web-media to discuss concepts and ideas with the students.

Tutorial sessions in both groups involved students working on problems in groups and presenting their solutions to the rest of the class. These problems were from standard tutorials from the previous year. The tutorial schedule is shown in table 4-2. Samples of tutorials are found in appendix E.

For both groups, students had the same total time-on-task of 15 hours, 3 hours per day. A survey was conducted on the last day of training. Group I and II had different survey questionnaires based on their training experience. The formal written test was conducted the following day, the 6th day. The test lasted 1 hour. Both groups took the test at the same time and the seating arrangement was randomised. The test script was collected in the same manner to ensure the marker would mark the scripts "blind" (i.e. without knowing which group the student script belong to). This was to ensure that there were no elements of bias in the marking of the script.

An initial analysis of the questionnaire was performed in the week between the study and the interview. This was to allow analysis to be carried out, and the identification of further questions, to be put to the students during the interview sessions. The analysis took 3 days, questions to be identified took the next 2 and the interview questions and planning were set out in the last 2 days. Once that was done, the interview schedule was sent to the selected students and the interview was conducted on a chosen day, one week later. Before each interview, the purpose of the interview was explained to the student and permission was sought to tape the interview session. The interview sessions were taped using a micro-cassette recorder and a transcript of each session was produced.

4.10 Expected Results

It was anticipated that students using VE in Group I would achieve moderately better results in the quantitative test than the students in Group II using the traditional approach. The conclusions to be drawn from this exploratory study hinged on the development, or construction of meaning from the use of virtual environments. By using a variety of formats and through the process of personal experimentation, evidence of deductive reasoning in addition to gains in student content knowledge was expected. The use of the VRCIM environment is an intensive undertaking that requires deep understanding of the processes involved in CIM coupled with the skills to make that understanding manifest as workable solutions on the system.

4.11 Method of Analysis

The data collected via the written test was used to analyse if the hypothesis was supported. Besides using the overall result as a comparison between the two groups, further details of the learning were obtained via question-by-question analysis. The written test was used to investigate the first research question, "Did VR technology help improve students' learning processes when compared to traditional classroom methods?"

Each of the questions 1 through 33 of the survey questionnaires collected was analysed using a frequency distribution and t-test. Principal component analysis was not used in this case as the method needs a sample size that is at least twice the number of variables (Foster 1998). The number of variables in this case was 20, which meant that the sample size had to be at least 40 students from each group. The finding from this section of the questionnaire was used to provide further information for investigating research question 1, as well as to shed further light on research question 5 ("Were students still able to collaborate while learning through a VR environment?" and research question 6 ("Did students prefer VR as a learning tool over traditional methods").

Questions 34 through 37 in the questionnaire were used to identify important factors in VR that the students felt helped in supporting the learning process as well as to find out what motivates the students. These were used to provide findings for research question 2 ("Which aspects of using VR assisted the learning process"), question 3 ("Were students motivated through the VR experience?") and question 4 ("Which aspect of using VR motivated the students?")

Analysis of question 38 of the questionnaire was to collect information on students' learning strategies. The concept map analysis was conducted using the information (sketches and notes) provided by students from the two groups in question 38. Students were asked to show the strategy they adopted to enable them to understand the topic and to solve learning problems in the subject area. In other words, this analysis sought to find out:

a). if there was a difference in strategies adopted by Group I and Group II, and

b). what models were used by each group to facilitate learning

In this analysis, a study was made to isolate the common "anchors" indicated by the notes and diagrams drawn by the students from each group. These were then measured by looking at the number of occurrences. This was used to support findings to research question 1.

Interviews were conducted two weeks after the training and test. The main aim of the interview sessions was to provide a deeper understanding of the use of VR in augmenting the learning process by delving deeper into the students' comments in the survey forms. The interviews were recorded and transferred to paper transcripts. The responses from the students were then analysed. The interview session was used to collect information on questions that arose after analysis of the questionnaire. It also provided a means to capture information "live" from the students by collecting other data not captured by text-based data.

PART III

RESEARCH

5. FINDINGS I: RESULTS OF OBJECTIVE TEST & LIKERT SCALE SECTION OF SURVEY QUESTIONNAIRE

5.1 Overview

Statistical analysis was conducted on all of the measures collected: formal objective tests from Group I (VR Augmented Group) vs. Group II (Traditional Group), frequency distribution comparisons within each group and across groups in the survey questionnaire and interview data for students. A "Progressive Focussing" method as espoused by Parlett & Hamilton (1976), was used in the analysis. The process allowed data to be collected over a wide angle, reviewed, and followed by in-depth investigation. This started off with using an objective test to investigate if VR technology helped improve students' learning processes, followed by a survey questionnaire to investigate the aspects involved and finally, interview sessions to study in-depth issues arising from information sieved from the questionnaire. Chapter 5 describes the findings from the objective test and the Likert Scale questions in the questionnaire. Chapter 6 describes the findings from the essay questions and concept diagrams from the survey questionnaire as well as the interview session. The chapters were separated as the results from the analysis were too extensive to put into one chapter.

5.2 Objective Test

20 students from each group participated in the test. The main aim of this analysis was to determine if VR augmentation helped student performance in a common-test situation. A 2-tailed t-test was used in the analysis of the test scores. The independent t-test, together with effect size calculations was used. As indicated in section 4.8, the effect size (d), reflects how

large the effect of an independent variable was, that is, the degree to which the phenomenon is present in the population (Burns 2000). More recently, statistical significance on its own has been seen as an unacceptable index of effect (Thompson 1998, Thompson & Snyder 1997, Fitz-Gibbon 1997) because it depends on sample size. What is also required to accompany significance is information about effect size, which helps to indicate the extent of differences in the means and variances. Hence, the larger the difference between the two population means, the greater the effect size; the smaller the variance within the populations, the greater the effect size. The independent t-test comparing the overall results obtained during the test showed that there was no significant difference in the score obtained by Group I (VR Augmented Group) and Group II (Traditional Group) students. Effect size was 0.44. At first glance, this suggested that VR Augmentation did not help students' performance in the written tests in the CIM subject to a statistically significant context. Table 5-1 shows the results obtained.

	Mean ($\bar{x}$)	**Median**	**Std. Dev. (σ)**	**Variance (σ^2)**	**t-test * (df = 38, p < 0.05)**
Group I VR Augmented Group (n=20)	69.55	73.5	17.33	300.37	t = 1.409 (p= 0.167) d=0.44 Not Significant
Group II Traditional Group (n=20)	60.60	62.00	22.51	506.67	
*assumption on equal variances tested					

Table 5-1: T-test of the overall test scores in both Group I and Group II Samples

Figure 5-1 shows the box plot of the two samples. The gap between the upper and lower ranges of Group I appeared to be smaller than that of Group II (61.0 vs. 87.0). The middle 50% of scores (the inter-quartile range) in Group I was slightly smaller (20.75 vs. 22.0), suggesting that there was less variation in the understanding of the topic. Group I has a mean value of 69.55 compared to 60.60 in Group II. The individual analysis of questions in the test yielded more results. A summary is shown in table 5-2. Full detail of the analysis can be found in Appendix F.

The past-year term paper examined the students based on a number of criteria needed for the subject. Criteria such as memory work and its application, the application of formulae and problem solving were tested. Individual analysis showed that in questions 1, 2 and 3, there were no significant difference in terms of scores but there was a significant difference in question 4. Questions 1, 2 and 3 were all questions that dealt with memory work and the application of formulae while question 4 dealt with problem solving skills.

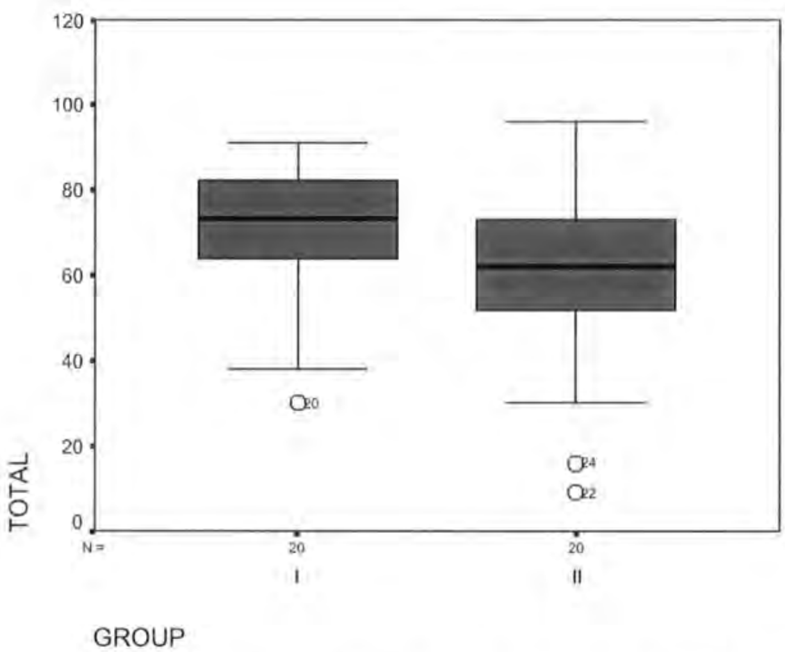


Figure 5-1: Box Plot of the overall test score between Group I and Group II samples

Test Questions	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* (df = 38, p < 0.05)	Question Type
	Group I	Group II		
Q1 (20marks)	8.65 *(6.79)*	7.35 *(6.063)*	t = 0.639 (p= 0.527) d=0.20 Not Significant	Memory work & application
Q2 (20marks)	11.30 *(6.00)*	9.25 *(7.181)*	t = 0.980 (p= 0.333) d=0.31 Not Significant	Memory work & ability to differentiate
Q3 (20marks)	14.85 *(6.27)*	14.30 *(6.90)*	t = 0.264 (p= 0.793) d=0.08 Not Significant	Memory work & application of formulae
Q4 (40marks)	34.75 *(4.789)*	29.70 *(9.319)*	t = 2.155 (p= 0.038) d=0.68 Significant	Problem solving skills & calculations
*assumption on equal variances tested				

Table 5-2: t-test of individual question in both Group I and Group II Samples

It was noted that consistently, the mean scores of Group I students were higher than Group II students. For example, the overall mean score for Group I was 69.55 compared to 60.60 and the same tendency was evident in the mean score for individual questions: Question 1 (8.65 vs. 7.35), Question 2 (11.30 vs 9.25), Question 3 (14.85 vs. 14.30) and Question 4 (34.75 vs. 29.70). Although the scores only reached statistical significance in question 4, where problem-solving skills were needed, the overall analysis suggested that VR augmentation helped in facilitating better performance.

5.3 Likert Scale Section of Survey Questionnaire

The analysis of the survey questionnaire was divided into 4 sections, according to the format of the questionnaire, which contained a Likert Scale section, a section on essay questions, a section on ranking and lastly, a concept map of the problem solving approach. There were altogether 20 respondents from Group I and 20 respondents from Group II. Details of the survey analysis can be found in Appendix G. Chapter 5 highlights the Likert Scale analysis while the essay question analysis, the ranking analysis and the concept map analysis are shown in chapter 6.

There were altogether 33 such questions. The aim of this analysis was to determine what the students felt were the main activities that contributed to their learning. A 4-point Likert Scale was used. Each of the 33 questions from both Group I and II was analysed according to their frequency distribution in four categories, "Strongly Agree", "Agree", "Disagree" and "Strongly Disagree", according to the grouping of learning activities shown previously in table 4-4. Additionally, an independent 2-tailed t-test, at 0.05 level of significance was used on each question to determine if there was a difference in the mean score of Group I and Group II students.

In complementary questions 14, 16, 18, 22, 23, 28, 29, 32 and 33, frequencies were rotated in the analysis so that "Strongly Agree" was registered as the strongest possible score in both Group I and II samples. This meant that questions 14, 16, 28, 29, 32, 33 in Group I were rotated and questions 18, 22, 23 in Group II were rotated. In addition, questions 19, 21 and 30 in both groups were rotated for the same reason. These were "negative" questions, which reflected that "Strongly Disagree" was the highest possible score. The following example illustrates the idea of "rotation".

In Group I, the group that experienced VR augmentation, question 22 was phrased as:

"I learnt faster in a VR environment compared to traditional methods."

In Group II, the traditional learning group, question 22 was phrased as:

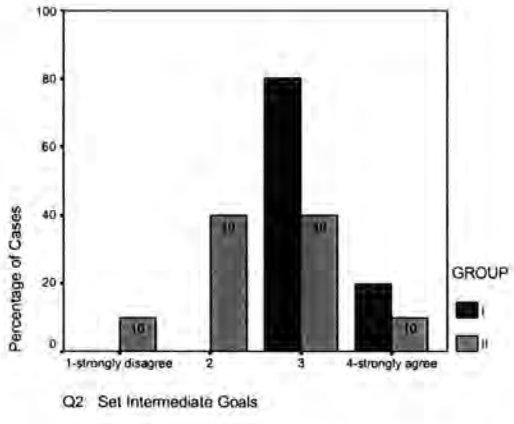
"I believe I learnt faster in a traditional environment compared to what I know of the VR environment."

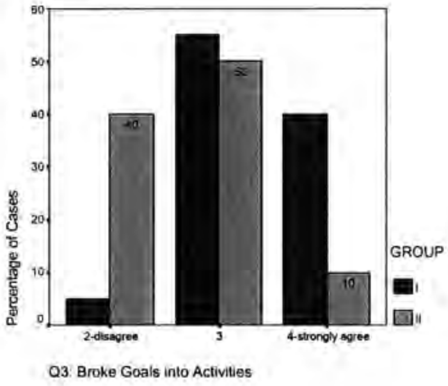
Hence, to compare the frequencies in equal dimensions where "Strongly Agree" reflected the highest score in the positive sense, Group II scores were rotated. This meant that every "Strongly Disagree" score was converted to "Strongly Agree" and "Disagree" was converted to "Agree" and vice versa.

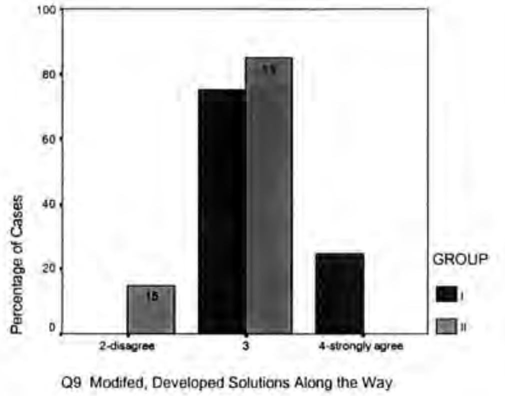
In calculating the mean value of the t-test, "Strongly Agree" was scored as a 4, "Agree" as 3, "Disagree" as 2 and "Strongly Disagree" as 1. Levene's Test was used in testing the equality of variances. Where the test failed, equal variances were not assumed in the t-test calculation. SPSS was used to perform the calculations. Out of the 33 questions, questions 2, 7, 10, 13, 18, 21, 22, 23, 24, 25, 29, 30 and 33 failed Levene's Test for Equality of Variances and for these questions, equal variances was not assumed in the t-test calculations. The section below summarises the findings.

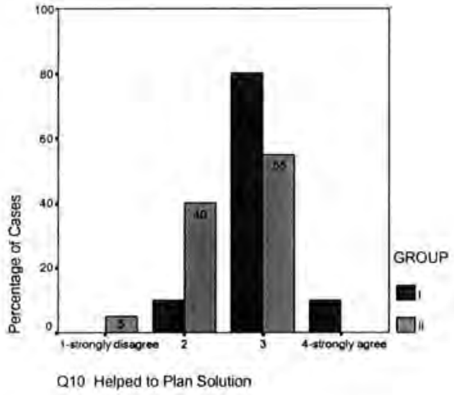
5.3.1 Planning

Questions 2, 3, 9 and 10 were related to planning as referenced in table 4-4. From figure 5-2, the VE used appeared to have helped Group 1 students in the planning phase in studying the subject. Both distributions of Group I and II in the 4 questions appeared to be skewed towards the right with Group II data following closer to the pattern of a Normal curve. 100% of Group 1 students (80% Agree, 20% Strongly Agree) indicated that they were able to set intermediate goals compared to 50% (40% Agree, 10% Strongly Agree) of Group II students.









Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* (p < 0.05)
	Group I	Group II	
2	3.20 *(0.41)*	2.50 *(0.83)*	t = 3.39 (p= 0.00, d=1.07) Significant
3	3.35 *(0.59)*	2.70 *(0.66)*	t = 3.30 (p= 0.00, d=1.04) Significant
9	3.25 *(0.44)*	2.85 *(0.37)*	t = 3.11 (p= 0.00, d=0.98) Significant
10	3.00 *(0.46)*	2.50 *(0.61)*	t = 2.94 (p= 0.01, d=0.93) Significant
*assumption on equal variances tested			

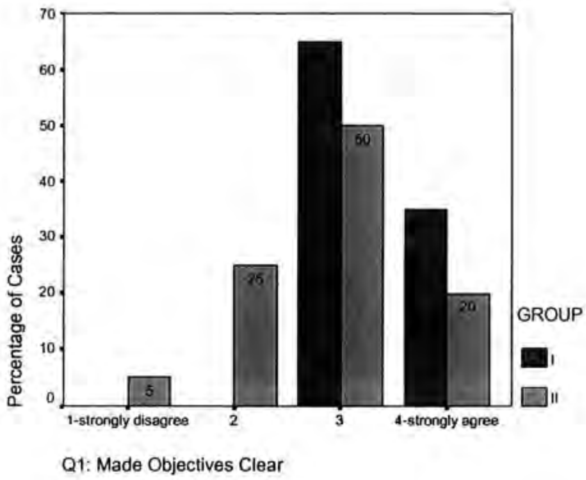
Figure 5-2: Analysis of data on planning

In terms of the t-test, the difference between the mean scores of Group I and Group II was statistically significant (t=3.39, p=0.00, d=1.07). Group 1 students (95%) also indicated that they were able to break goals into activities (55% Agree, 40% Strongly Agree) while only 60% (50% Agree, 10% Strongly Agree) of Group II students indicated this. The t-test score indicated that there was a significant difference (t=3.30, p=0.00, d=1.04).

The VE seemed to encourage students to break larger problems into smaller solvable ones. This was largely due to way the system was designed, steering students towards solving problems in parts. In question 9, 100% (75% Agree, 25% Strongly Agree) of Group 1 students indicated that they were encouraged to modify and develop their solutions as they work towards solving the simulated problem. 85% (85% Agree, 0% Strongly Agree) of Group II students agreed that the traditional method helped them to modify and develop models to solve problems. It was felt that the VR system with its emphasis on experimentations, i.e. for students to form and to test their hypothesis (with the capability to see the simulated results instantly), contributed largely to their being able to modify their solutions. This was supported by the t-test ($t=3.11$, $p=0.00$, $d=0.98$). Overall, 90% of students (80% Agree, 10% Strongly Agree) in Group I indicated that the virtual environment helped them to plan, compared to 55% (55% Agree, 0% Strongly Agree) of Group II students who indicated that the traditional system helped them in their planning. The t-test ($t=2.94$, $p=0.01$, $d=0.93$) further showed that this statement was statistically significant. The large effect sizes, indicated by Cohen (1992) to be a value more than 0.8, indicated that the statistical power is higher (Burns 2000), in turn suggesting that VR augmentation program had a high impact on these activities.

5.3.2 Goal Setting

Only question 1 asked about goal setting. 100% of Group I students (65% Agree, 35% Strongly Agree) replied that VE helped in making objectives clear in the subject while 70% (50% Agree, 70% Strongly Agree) in Group II indicated the same for the traditional method. Figure 5-3 showed that Group I's distribution drifted towards the extreme positive position while that of Group II followed a Normal curve. This implied that in Group I students' opinion, the VE had played a major role in helping them to identify goals and objectives compared to Group II. Statistically, the t-test ($t=2.36$, $p=0.02$, $d=0.75$) also supported this finding.

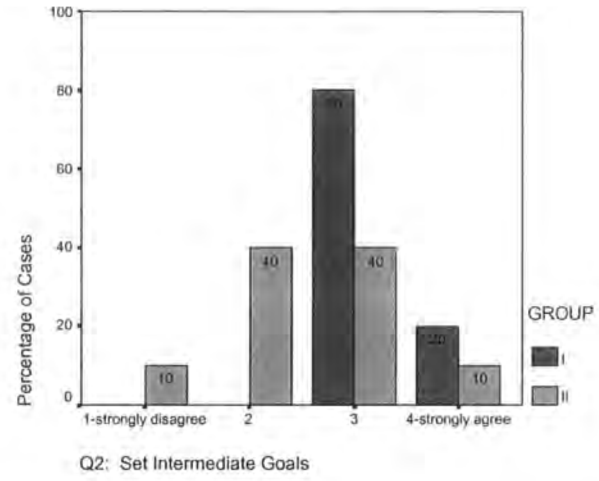


Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
1	3.35 *(0.49)*	2.85 *(0.81)*	t = 2.36 (p= 0.02, d=0.75) Significant
*assumption on equal variances tested			

Figure 5-3: Analysis of data on goal setting

5.3.3 Sub-Goals

Setting of sub-goals is one component of planning. In this section, a closer look is directed at this question. Whilst Group I's distribution was at the positive extremities, (80% Agree, 20% Strongly Agree), Group II's distribution appeared to follow the Normal curve. Group II students indicated only 50% (40% Agree, 10% Strongly Agree) agreement that the traditional method helped them to set intermediate goals in their planning. This was a very strong indication that VE was able to help students identify goals and activities and de-construct them into sub-goals and sub-activities. In order to do this, the students had to understand the hierarchy of the problem structure, leading to meaningful learning. How students see this problem structure is discussed in section 6.4, which throws light on students' replies to question 38 of the questionnaire. Section 5.3.4 further discussed the issue of meaningful learning. The t-test in question 2 indicated a significant difference between the mean scores of Group I and Group II students at t=3.39, p=0.00, d=1.07. The calculations also showed a large effect size in the analysis of the sub-goals.

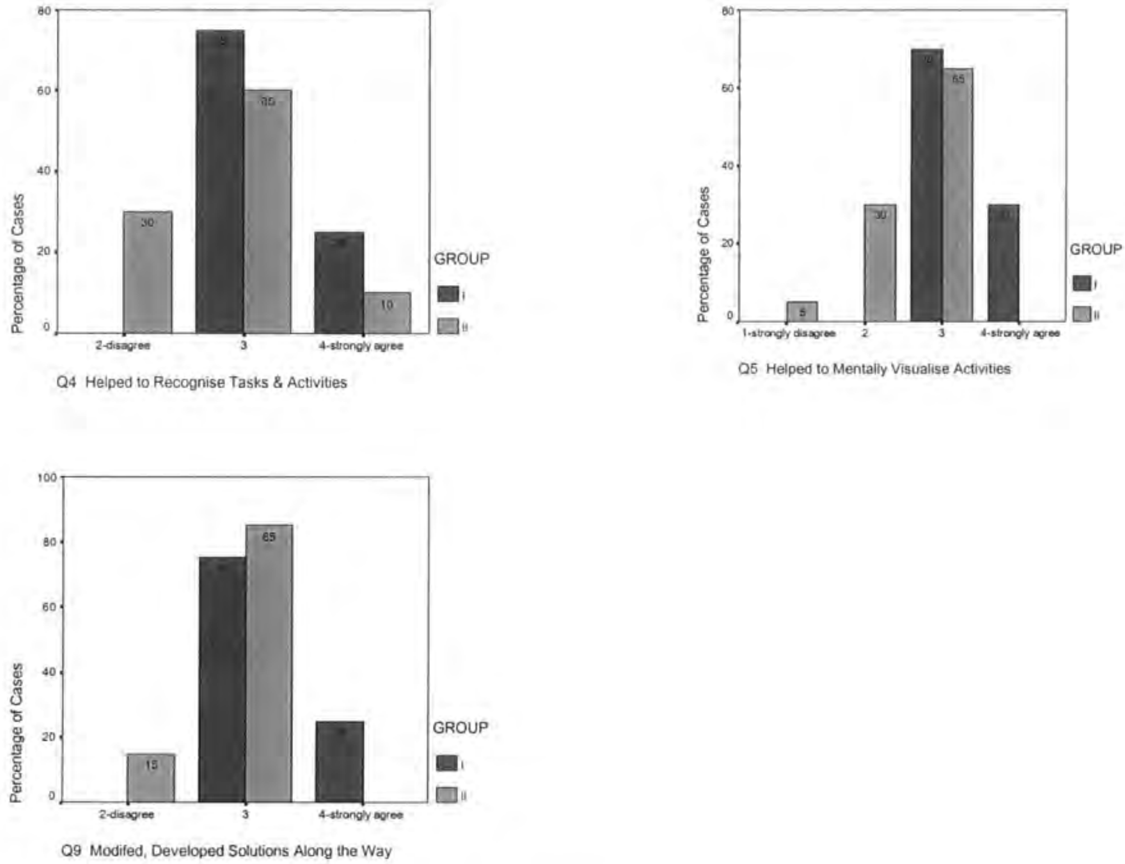


Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
2	3.20 *(0.41)*	2.50 *(0.83)*	t = 3.39 (p= 0.00, d=1.07) Significant
*assumption on equal variances tested			

Figure 5-4: Analysis of data on setting sub-goals

5.3.4 Improved Understanding

Questions 4, 5 and 9 were analysed for this learning activity. Figure 5-5 showed that the VE helped Group I students to improve their understanding of the subject. In question 4, 100% of students from Group I (75% Agree, 25% Strongly Agree) indicated that the VE helped them recognise tasks and activities they needed compared to 70% of students from Group II (60% Agree, 10% Strongly Agree) who indicated that traditional methods helped them recognise the tasks and activities. Statistics showed that there was a significant difference (t=2.65, p=0.01, d=0.83) in the score between Group I and II students. Students were able to pick out and identify activities and tasks from the many other tasks in the VE.



Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test ($p < 0.05$)
	Group I	Group II	
4	3.25 *(0.44)*	2.8 *(0.62)*	t = 2.65 (p= 0.01, d=0.83) Significant
5	3.30 *(0.47)*	2.60 *(0.60)*	t = 4.11 (p= 0.00, d=1.30) Significant
9	3.25 *(0.44)*	2.85 *(0.37)*	t = 3.11 (p= 0.00, d=0.98) Significant
*assumption on equal variances tested			

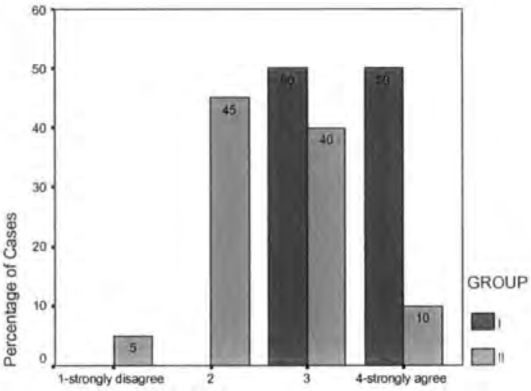
Figure 5-5: Analysis of data on improving understanding

Students would have to understand the subject and the problems in order to do this. Question 5 of the questionnaire showed that 100% of students from Group I (70% Agree, 30% Strongly Agree) indicated that the VE helped them to mentally visualise the activities compared to 65% of Group II (65% Agree, 0% Strongly Agree) students who indicated this for the traditional method. Again, there was a significant difference between the means (t=4.11, p=0.00, d=1.30) of Group I and II students. This was the main reason why students appeared to have a better understanding in Group I.

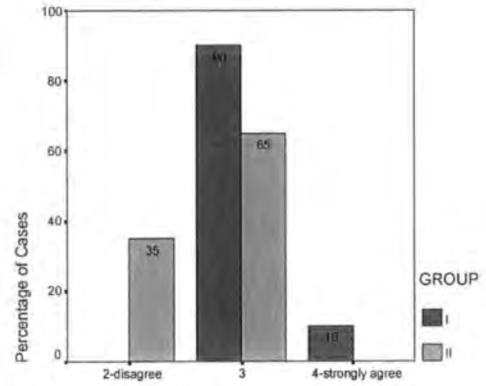
As a result, 100% of students (75% Agree, 25% Strongly Agree) in Group I agreed that the VR system helped them to modify and developed their solutions as they worked towards solving the simulated problem. As they worked on the VE, they appeared to improve their understanding and were able to flexibly modify their solutions. 85% of respondents (85% "Agree", 0% "Strongly Agree") in Group II agreed that the traditional course helped them to develop their mental model of the topic. Statistically, the t-test showed that there was a difference between the two means (t=3.11, p=0.00, d=0.98) of Group I and II in question 9. Effect size value was high throughout the analysis for improved understanding, ranging from 0.83 to 1.30.

5.3.5 Trial & Feedback

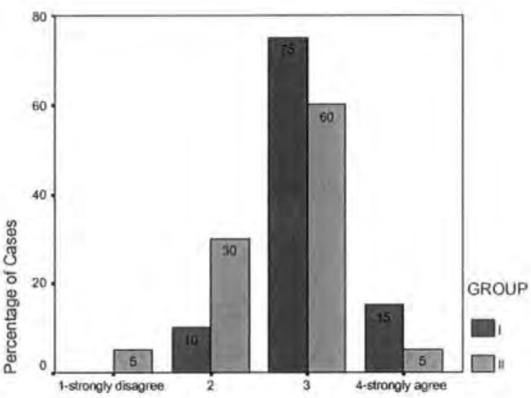
Questions 6, 7, 13, 15 and 16 were analysed. The trial and error feature in the VE appeared to have helped Group I students in their learning of the subject. From figure 5-6, 100% of students from Group I (50% Agree, 50% Strongly Agree) indicated that the VE allowed them to test each activity until they were satisfied before moving on to the next while 50% of Group II students (40% Agree, 10% Strongly Agree) indicated that this was so. The difference between the means of Group I and II was statistically significant at t= 4.64, p=0.00, d=1.47. By allowing the Group I students to carry out this process, the VE allowed them to locate their mistakes, correct them and to learn from the experience. This was shown in question 7 where 100% of Group I students (90% Agree, 10% Strongly Agree) in the analysis indicated that they could easily find out where their mistakes were and correct them compared to 65% of Group II respondents (65% Agree, 0% Strongly Agree). The difference between the means of Group I and Group II scores was significant at t=3.48, p=0.00, d=1.1.



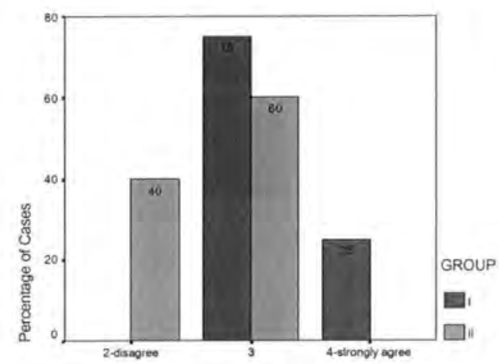
Q6 Helped Test Activity before Moving to the Next



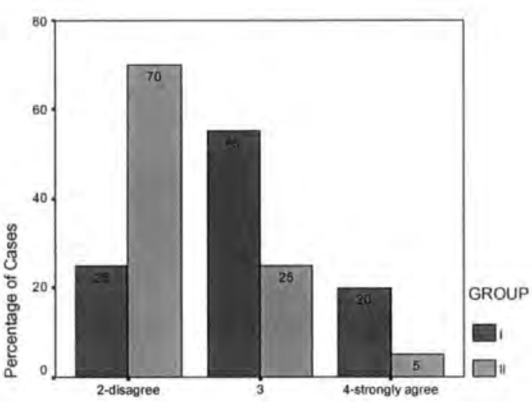
Q7 Helped Locate Mistakes & Correct



Q13 Able to Try Out Different Ideas



Q15 Allowed Instant Feedback



Q16 Preferred to Test Solutions on the Computer

Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
6	3.50 *(0.51)*	2.55 *(0.76)*	t = 4.64 (p= 0.00, d=1.47) Significant
7	3.10 *(0.31)*	2.65 *(0.49)*	t = 3.48 (p= 0.00, d=1.10) Significant
13	3.05 *(0.51)*	2.65 *(0.67)*	t = 2.12 (p= 0.04, d=0.67) Significant
15	3.25 *(0.44)*	2.60 *(0.50)*	t = 4.33 (p= 0.00, d=1.37) Significant
16	2.95 *(0.69)*	2.35 *(0.59)*	t = 2.97 (p=0.01, d=0.94) Significant
*assumption on equal variances tested			

Figure 5-6: Analysis of data on trial and feedback

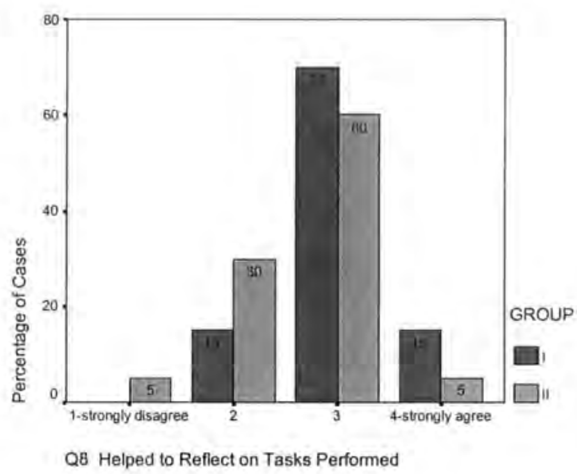
Question 13 showed that 90% of Group I students (75% Agree, 15% Strongly Agree) indicated that the VE allowed them to explore/try out different ideas while 65% of Group II respondents (60% Agree, 5% Strongly Agree) indicated that this was so for the traditional method. The difference between the mean scores of both Group I and II was also statistically significant (t=2.12, p=0.04, d=0.67).

Question 15 showed that 100% of Group I students (75% Agree, 25% Strongly Agree) indicated that the VE provided instant feedback on their ideas while 60% of Group II respondents (60% Agree, 0% Strongly Agree) indicated this for the traditional method. The difference between the means was statistically significant at t=4.33, p=0.00, d=1.37. Through exploration, and the ability to conduct trials and obtain instant feedback, Group I students were able to achieve better understanding of the subject.

Meaningful learning also appeared to have taken place. 75% of Group I students (55% "Agree", 20% "Strongly Agree") in question 16 indicated that they learnt better from testing their solutions in the VE rather than from communicating directly with instructors or with friends. Only 30% of Group II respondents (25% "Agree", 5% "Strongly Agree") said the same thing. Statistically, the difference in means between the 2 groups in question 16 was significant at t=2.97, p=0.005, d=0.94. Data on trial and feedback indicated a high effect size value in all the cases.

5.3.6 Reflection

Question 8 was analysed. Figure 5-7 showed that 85% of Group I students (70% Agree, 15% Strongly Agree) indicated that the VE system enabled them to look back and reflect on work done compared to 65% of Group II students (60% Agree, 5% Strongly Agree) who indicated that the traditional method allowed them to do so. In section 5.3.5, it was shown that Group I students tended to explore, develop, try new ideas, more than their counterparts in Group II. Consequently they were able to look back and correct mistakes they made. Although the frequency chart and the group mean showed that Group I students were able to reflect on their work, the difference between Group I and II was not statistically significant as reflected in figure 5-7.

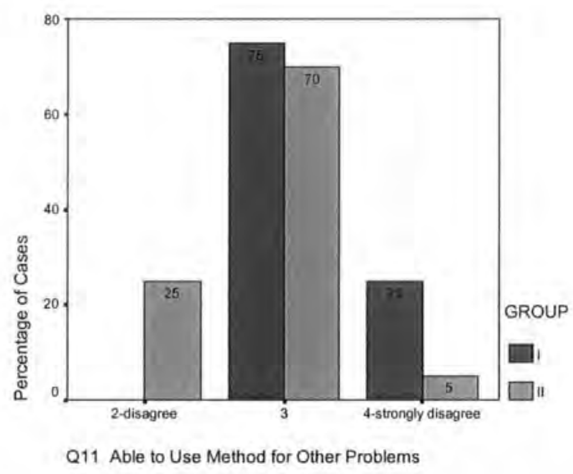


Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* (p < 0.05)
	Group I	Group II	
8	3.0 *(0.56)*	2.65 *(0.67)*	t = 1.8 (p= 0.08, d=0.57) Not significant
*assumption on equal variances tested			

Figure 5-7: Analysis of data on reflection

5.3.7 Abstraction

In the context of this experiment, abstraction represented the ability to detect relevant or critical information, leading to formation of generalised approaches to problem solving. This paved the way for students to develop the capability to solve other complex problems. Figure 5-8 showed that for question 11, 100% of students in Group I (75% Agree, 25% Strongly Agree) indicated that the same approach learnt in VE could be applied to other problems. 75% of students in Group II (70% Agree, 5% Strongly Agree) indicated that traditional methods learnt in class could be applied to other problems. The 100% representation in Group I showed that students saw themselves as able to demonstrate abstraction in their learning. The difference in means between Group I and II was statistically significant (t=2.93, p=0.01, d=0.93). The effect size of d=0.93 was large.

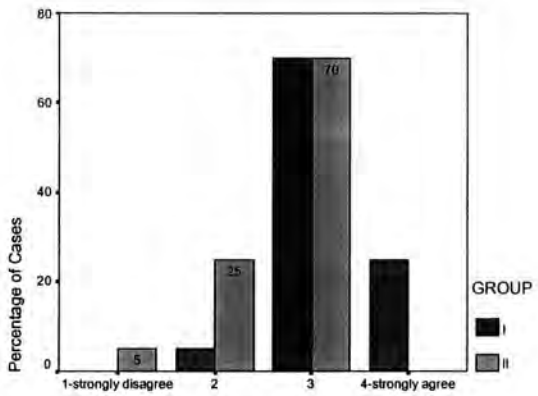


Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
11	3.25 *(0.44)*	2.80 *(0.52)*	t = 2.93 (p= 0.01, d=0.93) Significant
*assumption on equal variances tested			

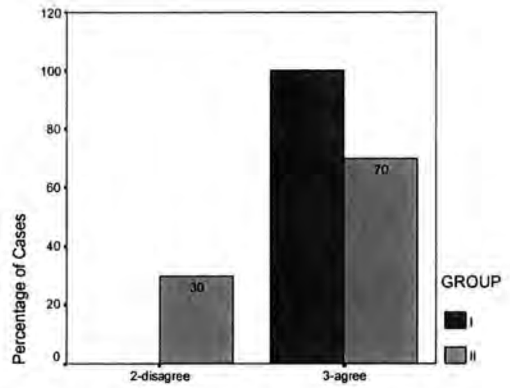
Figure 5-8: Analysis of data on abstraction

5.3.8 Active Involvement

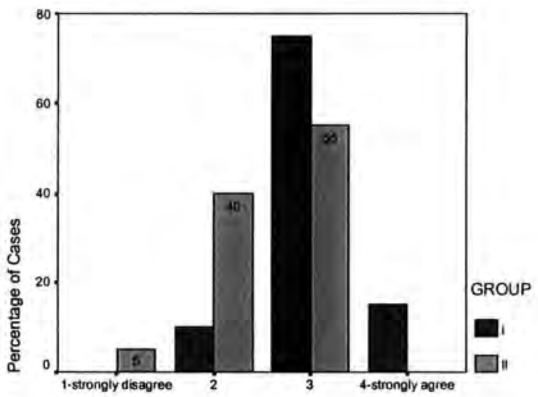
Questions 12, 24 and 25 were analysed. 95% of Group I respondents (70% Agree, 25% Strongly Agree) indicated that the VR system captured their attention and fostered active involvement.



Q12 Captured Attention & Foster Active Involvement



Q24 At times, Lessons Became a Reality



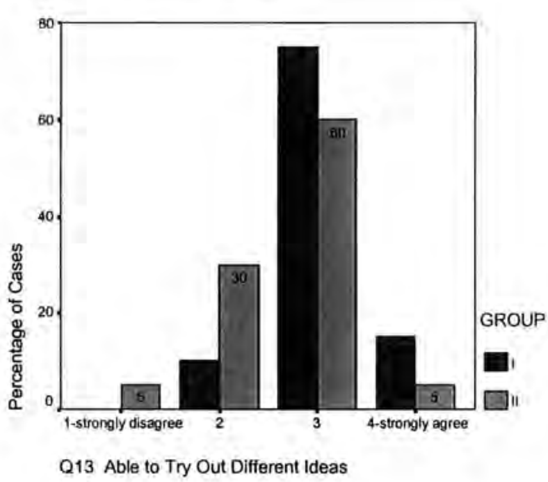
Q25 Understand Clearly How Actual System was Operated

Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test (p < 0.05)
	Group I	Group II	
12	3.20 *(0.52)*	2.65 *(0.59)*	t = 3.13 (p= 0.00. d=0.99) Significant
24	3.00 *(0.00)*	2.70 *(0.47)*	t = 2.85 (p= 0.01, d=0.90) Significant
25	3.05 *(0.51)*	2.50 *(0.61)*	t = 3.10 (p= 0.00, d=0.98) Significant
*assumption on equal variances tested			

Figure 5-9: Analysis of data on active involvement in learning

70% (70% Agree, 0% Strongly Agree) of Group II students indicated that traditional methods captured their attention and fostered active involvement. Students' responses from Group I clearly indicated that active learning was taking place in the VE. This was statistically significant at t=3.13, p=0.00, d= 0.99. Furthermore, in question 24, 100% of Group I students (100% Agree, 0% Strongly Agree) indicated that there were times the VE became a reality (i.e. they felt that they were involved to such an extent that they were immersed in the VE) while they were using it, compared to 70% of Group II students (70% Agree, 0% Strongly Agree) who said that the lesson became as real as the topic discussed. This was further confirmed by question 25 where 90% of Group I students (75% Agree, 15% Strongly Agree) indicated that they felt as if they were personally manipulating and running the actual system compared to 55% (55% Agree, 0% Strongly Agree) of Group II students. In both questions 24 and 25, the difference was statistically significant, respectively at t=2.85, p=0.01, d=0.90 and t=3.10, p=0.00, d=0.98. Hence, all the independent variables have a large effect on the test.

5.3.9 Divergent Thinking

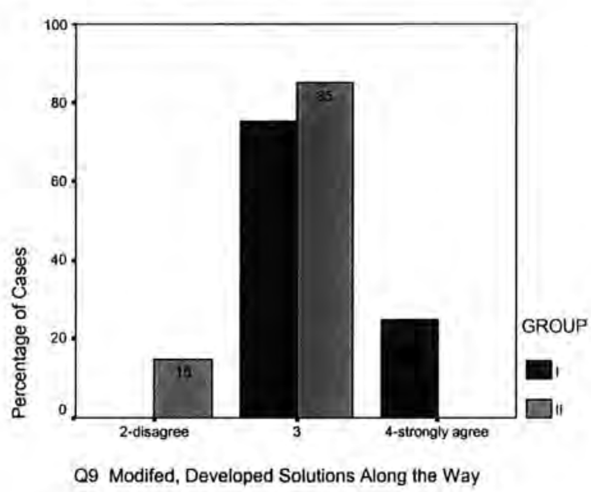


Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* (p < 0.05)
	Group I	Group II	
13	3.05 *(0.51)*	2.65 *(0.67)*	t = 2.12 (p= 0.04, d=0.67) Significant
*assumption on equal variances tested			

Figure 5-10: Analysis of data on divergent thinking

Question 13 was analysed. The question reflected on students' perception on being able to diverge their thinking by generating new ideas or scenarios and carrying out activities to test the ideas. 90% of Group I students (75% Agree, 15% Strongly Agree) indicated that the VE allowed them to explore/try out different ideas while 65% of Group II students (60% Agree, 5% Strongly Agree) indicated that this was so for the traditional method. Figure 5-10 showed that Group I students were comparatively more able to demonstrate divergent thinking. The scores also showed a statistical significance (t=2.12, p=0.04, d=0.67) between the means of Group I and II. The effect size value of 0.67 showed a medium to high effect on the test.

5.3.10 Convergent Thinking



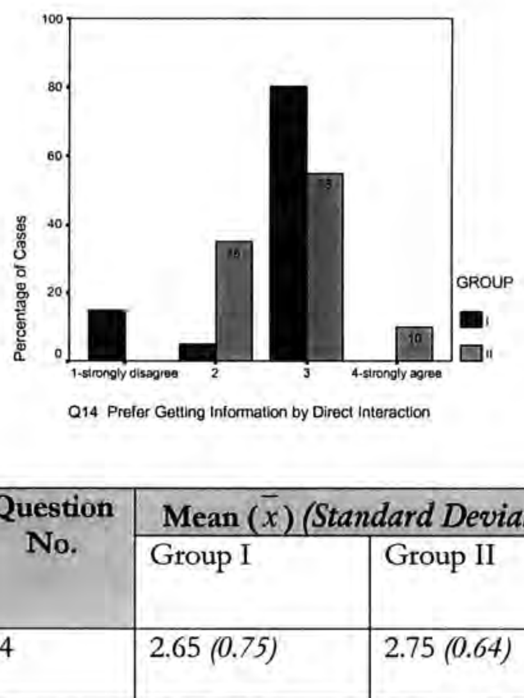
Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
9	3.25 *(0.44)*	2.85 *(0.37)*	t = 3.11 (p= 0.00, d=0.98) Significant
*assumption on equal variances tested			

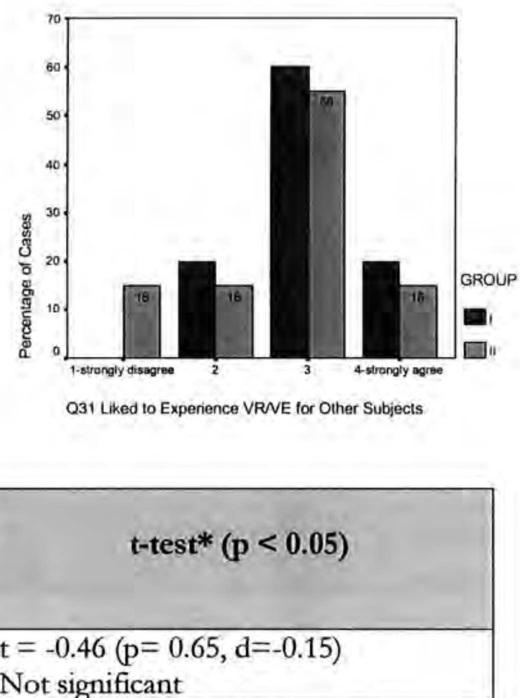
Figure 5-11: Analysis of data on convergent thinking

Question 9 was analysed. Convergent thinking allows learners to be able to logically think through ideas and then to converge them as solutions. This meant that they would need to slowly modify and evolve or develop their ideas as they worked towards understanding a problem and solving it. 100% of students (75% Agree, 25% Strongly Agree) in Group I agreed that the VR system helped them to modify and evolve their solution as they work whereas 85% of students (85% Agree, 0% Strongly Agree) in Group II agreed that the traditional course helped them to modify and evolve their understanding of the topic. The differences between the means of Group I and II were statistically significant at t=3.11, p=0.00, d=0.98. Thus, Group I students appeared to be ahead in converging understanding of the topic.

5.3.11 Learning Method Preference

Questions 14 and 31 were analysed. These questions were designed to find out if students preferred to discover information for themselves or they preferred to be taught. 80% of students in Group I (80% Agree, 0% Strongly Agree) preferred getting information by interacting with the VE than from getting information directly from lessons. 65% of students in Group II (55% Agree, 10% Strongly Agree) would have liked to have tried learning from VEs.





Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* (p < 0.05)
	Group I	Group II	
14	2.65 *(0.75)*	2.75 *(0.64)*	t = -0.46 (p= 0.65, d=-0.15) Not significant
31	3.00 *(0.65)*	2.70 *(0.92)*	t = 1.19 (p= 0.24, d=0.38) Not significant
*assumption on equal variances tested			

Figure 5-12: Analysis of data on learning method preference

Statistics in the t-test in figure 5-12 revealed that there was no significance in the difference between the means of Group I and II students regarding preference for direct interaction when getting information.

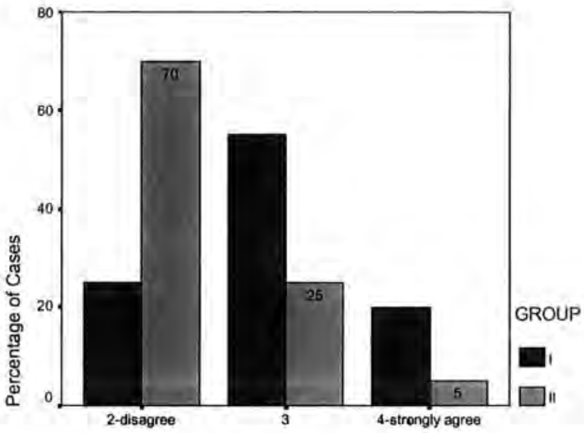
80% of students in Group I (60% Agree, 20% Strongly Agree) indicated that they would like to experience the use of VEs for other subjects while 70% of students in Group II (55% Agree, 15% Strongly Agree) felt that they could use VEs for other subjects. Like question 14, the difference between the means was not statistical significant ($t= 1.19$, $p=0.24$, $d=0.38$) showing that Group I students were not more likely to have wanted to experience the VR/VE environment for other subjects compared to Group II students although the mean was higher. The feedback indicated negative or low effect on the test.

The results showed that students in Group I who had experienced VR liked it (80% Agree) and would like to use the method for other subjects but there were no responses in "Strongly Agree" in question 14, signifying that there may be unknown factors involved. This was discussed in the interview session analysis, section 6.5. Group II students, who had not experienced VR, felt that they too would benefit from using the VR training environment.

5.3.12 Safe

Question 16 was designed to find out whether students learnt better by testing their solutions using VR/VE compared to discussing their problems with instructors and friends. 75% of Group I students (55% Agree, 20% Strongly Agree) indicated that they learnt better from testing their solutions in the VE compared to 30% of Group II students (25% Agree, 5% Strongly Agree) who said the same thing for traditional methods.

Factors involved in better learning were attributed to i) trial and feedback as shown in section 5.3.5 or ii) safety, allowing students the confidence to explore the environment as shown in sections 6.2 and 6.5.1. The difference between the means of Group I and II was statistically significant ($t=2.97$, $p=0.01$, $d=0.94$). The effect size was large.



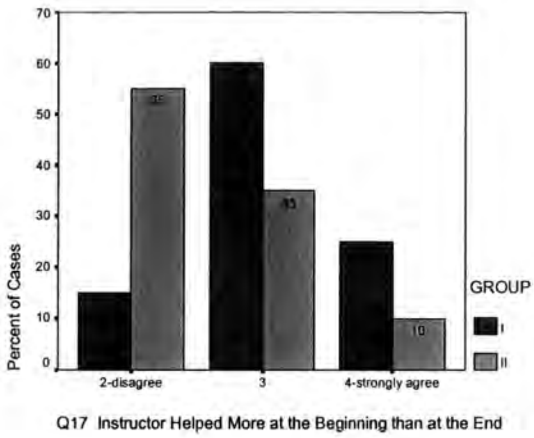
Q16 Preferred to Test Solutions on the Computer

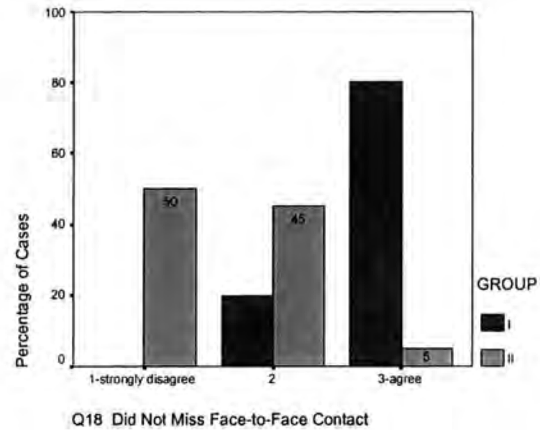
Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
16	2.95 *(0.69)*	2.35 *(0.59)*	t = 2.97 (p= 0.01, d=0.94) Significant
*assumption on equal variances tested			

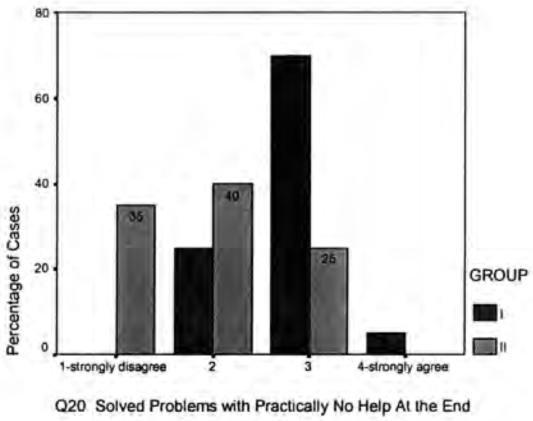
Figure 5-13: Analysis of data on safety

5.3.13 Self-Learn

Questions 17, 18 and 20 were analysed. These questions were designed to find out if students learnt to be independent and self-reliant during their learning process. In question 17, 85% of Group I students (60% Agree, 25% Strongly Agree) indicated that the instructor helped more at the beginning than at the end compared to 45% of Group II respondents (35% Agree, 10% Strongly Agree). The difference between the means was statistically significant at t=2.62, p=0.01, d=0.83. In question 18, 80% of Group I respondents (80% Agree, 0% Strongly Agree) reported that they did not miss face-to-face contact with the instructor compared to 5% (5% Agree, 0% Strongly Agree) in Group II. Again, the results showed statistical significance between the means at t=7.65, p=0.00, d=.42. This indicated that Group I students relied less on the instructor towards the end compared to Group II. The percentages in Group II appeared to be very low for "Agree" and "Strongly Agree". This was interesting, as it would indicate that Group II students were reliant on the instructor during the learning process.







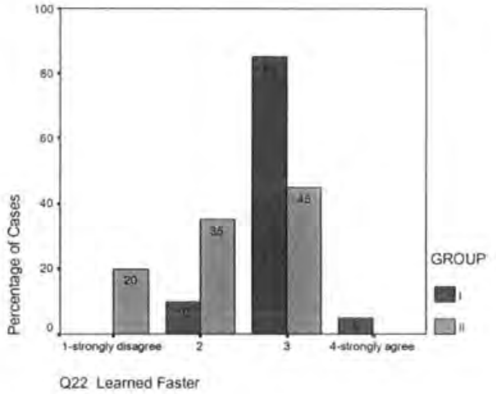
Question No.	**Mean ($\bar{x}$) *(Standard Deviation)***		**t-test* (p < 0.05)**
	Group I	Group II	
17	3.10 *(0.64)*	2.55 *(0.69)*	t = 2.62 (p= 0.01, d=0.83) Significant
18	2.80 *(0.41)*	1.55 *(0.60)*	t = 7.65 (p= 0.00, d=2.42) Significant
20	2.80 *(0.52)*	1.90 *(0.79)*	t = 4.26 (p= 0.00, d=1.35) Significant
*assumption on equal variances tested			

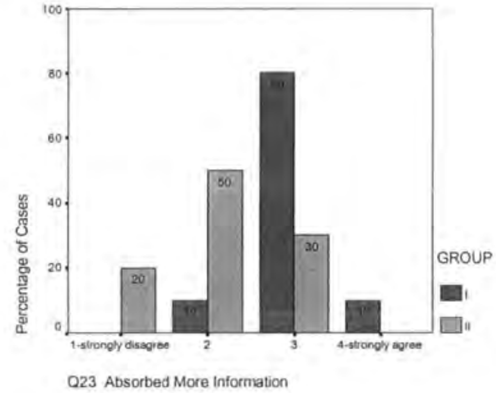
Figure 5-14: Analysis of data on self-learning

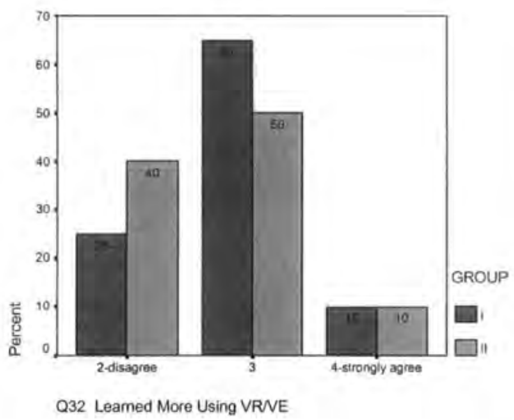
In question 20, 75% of Group I respondents (70% Agree, 5% Strongly Agree) indicated that they were able to solve problems with practically no help at the end compared to 25% (25% Agree, 0% Strongly Agree) of Group II respondents. The t-test showed that the difference between the means was statistically significant at t=4.26, p=0.00, d=1.35. Students in Group

I appeared to be more independent in problem solving. Section 6.5.2 further investigates this issue of independent learning. The effect sizes were large in all three cases.

5.3.14 Assimilation







Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
22	2.95 *(0.39)*	2.25 *(0.79)*	t = 3.56 (p= 0.00, d=1.13) Significant
23	3.00 *(0.46)*	2.10 *(0.72)*	t = 4.72 (p= 0.00, d=1.49) Significant
32	2.80 *(0.52)*	1.90 *(0.79)*	t = 0.76 (p= 0.45, d=0.24) Not significant
*assumption on equal variances tested			

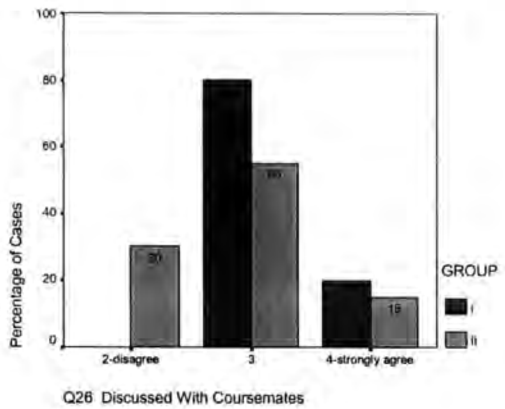
Figure 5-15: Analysis of data on assimilation

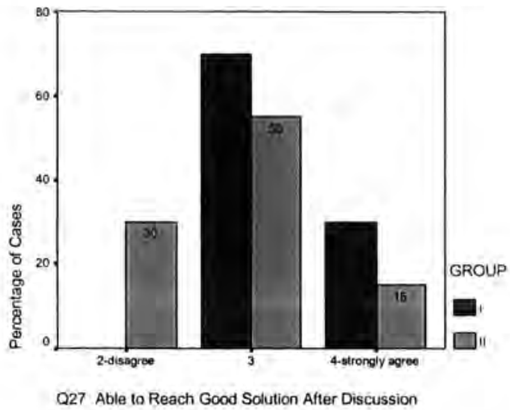
Assimilation occurs when a student perceives new objects or events in terms of existing schemes or operations. The three questions, 22, 23 and 32 were designed to find out if students in VR/VE were able to assimilate more information faster. In question 22, 90% of Group I students (85% Agree, 5% Strongly Agree) believed that they learnt faster in VE compared to 45% of Group II respondents (45% Agree, 0% Strongly Agree). In question 23, 90% of Group I students (80% Agree, 10% Strongly Agree) believed that they absorbed more information using VR as a learning tool compared to 30% of Group II students (30% Agree, 0% Strongly Agree). In question 32, 75% of Group I students (65% Agree, 10% Strongly Agree) believed that they could learn more from the VE compared to 60% of Group II respondents (50% Agree, 10% Strongly Agree). Figure 5-15 illustrates the results from these three questions, showing that Group I students believed that they were better assimilators. However, the t-test showed that while question 22 and 23 showed statistical significance between the two groups ($t=3.56$, $p=0.00$, $d=1.13$ and $t=4.72$, $p=0.00$, $d=1.49$ respectively), with Group I students feeling they performed better in terms of learning faster and absorbing more information, differences in question 32, on whether students felt they learnt more, were not statistically significant ($t=0.76$, $p=0.451$, $d=0.24$). Similarly, question 22 and 23 exhibited large effect size while question 32 showed a low effect size.

5.3.15 Collaboration

Questions 26 and 27 were analysed. The questions were designed to find out if collaboration was carried out and if they were successful collaborations. 100% of Group I students (80% Agree, 20% Strongly Agree) indicated that they discussed solving problems with their coursemates compared to 70% of Group II students (55% Agree, 15% Strongly Agree). The difference between the means of Group I and II just managed to qualify significance ($t=1.99$, $p=0.05$, $d=0.63$). 100% of Group I respondents (70% Agree, 30% Strongly Agree) indicated that they were able to reach a good solution faster after discussion with coursemates compared to 70% of Group II respondents (55% Agree, 15% Strongly Agree). In question 27, statistics ($t=2.46$, 0.02, $d=0.78$) showed that Group I students felt that they were more able to reach good solutions compared to Group II students. Figure 5-16 showed clearly that Group I students were more able to collaborate successfully compared to Group II students. However, questions that arose from these results were: what were the factors that lead to successful collaboration; and why was Group II less successful? These are shown in section 6.5.4.

Effect size values were in the range of medium to high.





Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
26	3.20 *(0.41)*	2.85 *(0.67)*	t = 1.99 (p= 0.05, d=0.63) Significant
27	3.30 *(0.47)*	2.85 *(0.67)*	t = 2.46 (p= 0.02, d=0.78) Significant
*assumption on equal variances tested			

Figure 5-16: Analysis of data on collaboration

5.3.16 Perceived Ease of Learning

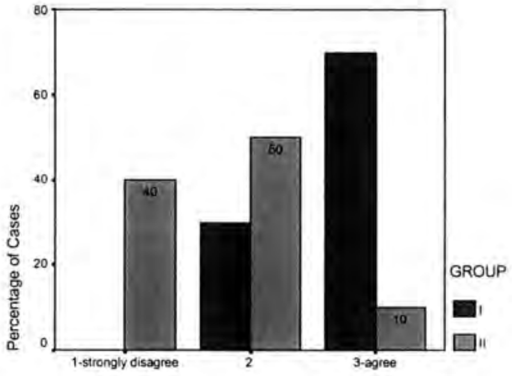
Questions 19, 21, 29, 30 and 33 were analysed. These questions were designed to find out whether using VR/VE was an easy experience. Whether getting over the technological barrier was difficult and whether the VR/VE system was comfortable to use.

In question 19, 70% of Group I students (70% Agree, 0% Strongly Agree) indicated that the new user interface of VR/VE would not be an obstacle to learning compared to 10% of Group II students (10% Agree, 0% Strongly Agree). There was a significant difference in the means of Group I and Group II at t=5.54, p=0.00, d=1.75). Hence, generally Group I students felt that the user interface was usable but there were still 30% of students in Group I who disagreed that the user interface was easy to ease. Also there were no responses in the "Strongly Agree" score. This signified that there were still factors that were holding back some students. These will be clarified in section 6.5.5 in the interviews.

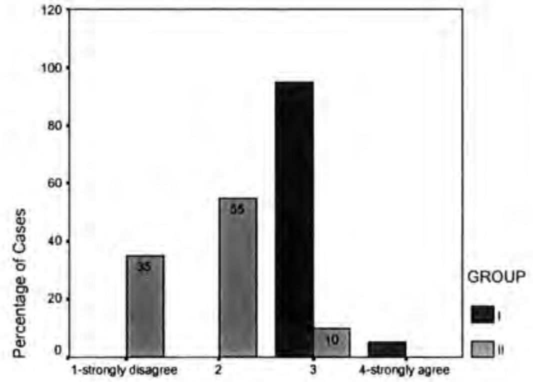
In question 21, 100% of Group I students (95% Agree, 5% Strongly Agree) indicated that they found it easy to use the VR system to arrive at the solution compared to 10% of Group II students (10% "Agree", 0% "Strongly Agree") who felt they that could not solve problems with it. The statistics showed a significant difference between the means of both groups of students at t=8.59, p=0.00, d=2.72). However, there is a contradiction for a minority group of students in Group II because on the one hand, these students felt that they would not be able to solve problems with the VR system, but on the other hand felt that the user interface problem could be over-come (10%) and VR/VE made learning easier (30%) in question 29. This issue will again be discussed in section 6.5.5.

In question 29, 85% of Group I students (80% Agree, 5% Strongly Agree) felt that using VR/VE as a learning tool made learning easier compared to 30% of Group II students (15% Agree, 15% Strongly Agree). Statistically, there was a significant difference in the feedback provided by Group I and II students (t=2.28, p=0.03, d=0.72). This question was used to verify that VR as a tool can enhance learning. The factors that made VR a good tool in enhancing learning are shown in latter sections.

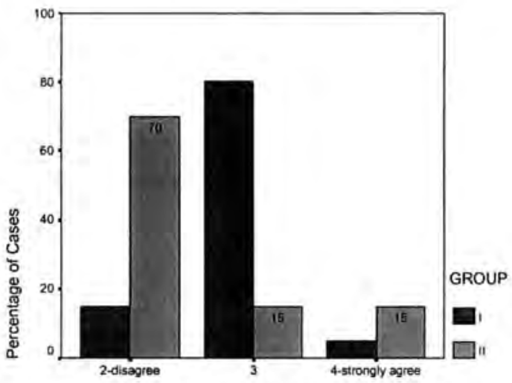
In question 30, 100% of Group I students (95% Agree, 5% Strongly Agree) agreed that VR/VE did not cause discomfort or disorientation when learning compared to 80% of Group II students (80% Agree, 0% Strongly Agree). This was because the VR/VE system used in this study was "Desktop VR" and not "Immersive VR" where the virtual environment is shown in the computer monitor and not through the use of specialised equipment such as head-mounted devices (HMD) or stereo-projection systems. This meant that whilst students were not completely "immersed" (i.e. they are aware of their current surroundings as well as able to talk to their coursemates), they were not affected by simulator sickness problems associated with the use of Immersive VR systems. Statistically, there was a significance in that Group I students had a stronger belief that VR systems did not cause discomfort during learning (t=2.39, p=0.02, d=0.76).



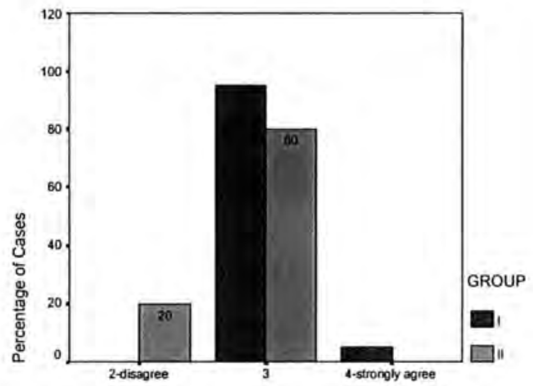
Q19 Learning the User Interface Not an Obstacle



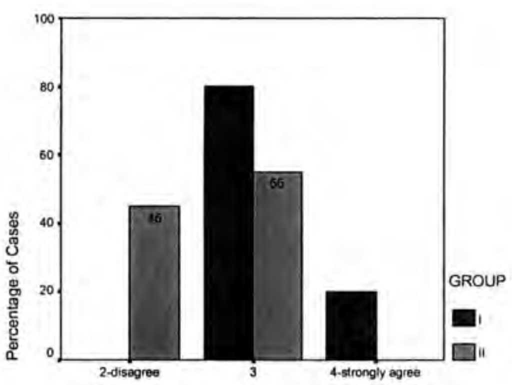
Q21 Did Not find it Difficult to Arrive at a Solution



Q29 VR/VE Made Learning Easier



Q30 VR/VE Causes Discomfort & Disorientation



Q33 Learning Using VR/VE was Less Painful

Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
19	2.70 *(0.47)*	1.70 *(0.66)*	t = 5.54 (p= 0.00, d=1.75) Significant
21	3.05 *(0.22)*	1.75 *(0.64)*	t = 8.59 (p= 0.00, d=2.72) Significant
29	2.90 *(0.45)*	2.45 *(0.76)*	t = 2.28 (p= 0.03, d=0.72) Significant
30	3.05 *(0.22)*	2.80 *(0.41)*	t = 2.39 (p= 0.02, d=0.76) Significant
33	3.20 *(0.41)*	2.55 *(0.51)*	t = 4.44 (p=0.00, d=1.40) Significant
*assumption on equal variances tested			

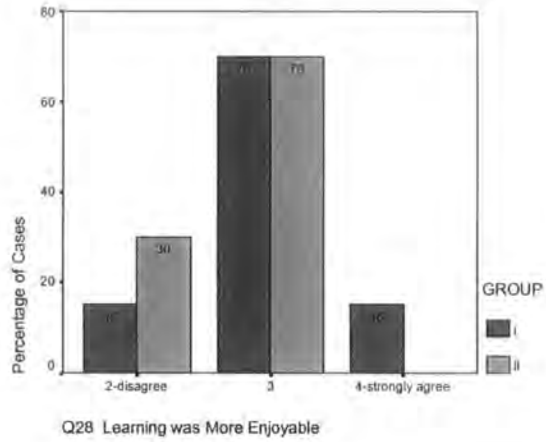
Figure 5-17: Analysis of data on perceived ease of learning

In question 33, 100% of Group I students (80% Agree, 20% Strongly Agree) found that overall, learning using VR/VE was not difficult and painful compared to 55% of Group II students (55% Agree, 0% Strongly Agree). Group I students had a stronger belief in this statement as shown in figure 5-17 (t=4.44, p=0.00, d=1.40).

Effect size calculations showed that the effect ranged from 0.72 to 1.75, indicating a large effect on the tests.

5.3.17 Enjoyment

Only question 28 was analysed. It has been shown that students' enjoyment in learning can be highly motivational (Youngblut 1997, Laurillard 1995). In question 28, 85% of Group I students (70% Agree, 15% Strongly Agree) indicated that learning was more enjoyable with VR/VE compared to traditional methods. 70% of Group II students (70% Agree, 0% Strongly Agree) also agreed that VR/VE was more enjoyable than traditional methods. However, there was no statistical evidence that Group I students enjoyed their learning experience more than Group II students (t=1.83, p=0.08, d=0.58).



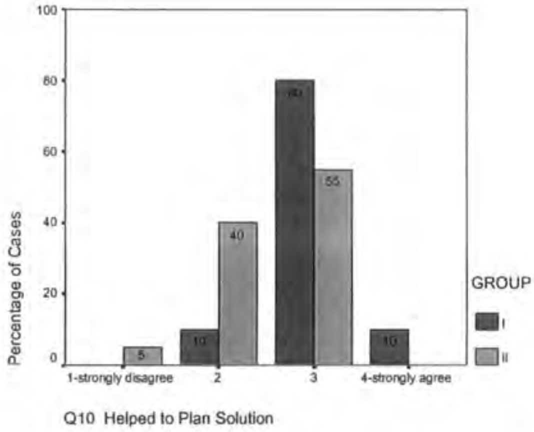
Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
28	3.00 *(0.56)*	2.70 *(0.47)*	t = 1.83 (p= 0.08, d=0.58) Not significant
*assumption on equal variances tested			

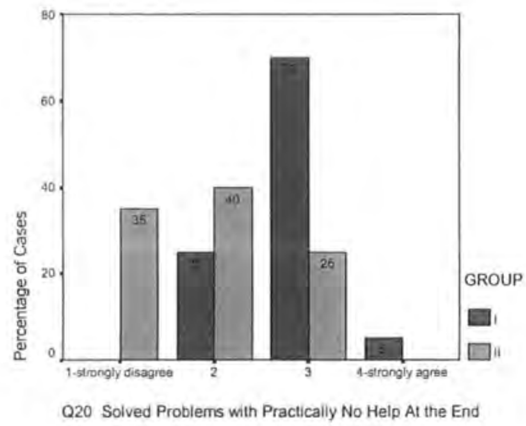
Figure 5-18: Analysis of data on enjoyment

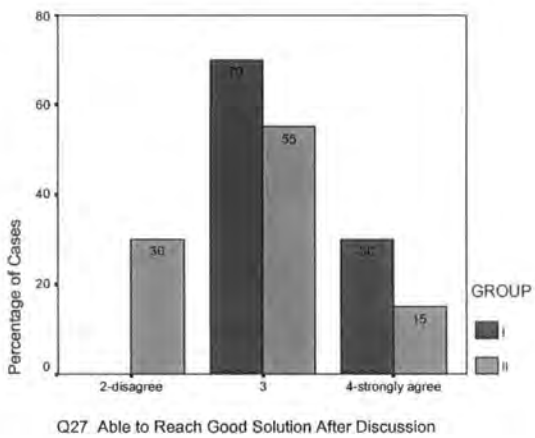
5.3.18 Problem Solving

Questions 10, 20 and 27 were analysed. These questions were developed to find out if VR/VE was able to enhance problem solving by helping in planning, ability to independently analyse and solve problems as well as to discuss and collaborate to reach better solutions. In question 10, 90% of students (80% Agree, 10% Strongly Agree) from Group I indicated that the VR augmentation programme helped them to plan to reach the solution while 55% of students (55% Agree, 0% Strongly Agree) indicated that the traditional methods helped them in their planning. The difference between the means of Group I and II students was significant (t=2.94, p=0.01, d=0.93), indicating that Group I students felt that VR/VE was able to enhance their planning compared to Group II students.

In question 20, 75% of Group I students (70% Agree, 5% Strongly Agree) indicated that they were able to solve problems with practically no help at the end compared to 25% (25% Agree, 0% Strongly Agree) of Group II students. Again, Group I students were shown to exhibit this ability more significantly (t=4.26, p=0.00, d=1.35) compared to Group II students.







Question No.	Mean ($\bar{x}$) *(Standard Deviation)*		t-test* ($p < 0.05$)
	Group I	Group II	
10	3.00 *(0.46)*	2.50 *(0.61)*	t = 2.94 (p= 0.01, d=0.93) Significant
20	2.80 *(0.52)*	1.90 *(0.79)*	t = 4.26 (p= 0.00, d=1.35) Significant
27	3.30 *(0.47)*	2.85 *(0.67)*	t = 2.46 (p= 0.02, d=0.78) Significant
*assumption on equal variances tested			

Figure 5-19: Analysis of data on problem solving

In question 27, 100% of Group I students (70% Agree, 30% Strongly Agree) indicated that they were able to reach a good solution faster after discussion with course mates compared to 70% of Group II students (55% Agree, 15% Strongly Agree). The statistics showed that there was a significant difference ($t=2.46$, $p=0.02$, $d=0.78$) between the means of Group I and Group II.

The independent variables in the three questions appear to have a large effect on the tests in problem solving. Hence, these results showed that VR/VE promotes planning, independence and collaboration in problem solving.

PART III

RESEARCH

6. FINDINGS II: RESULTS OF OPEN SECTIONS IN THE SURVEY QUESTIONNAIRE & INTERVIEW SESSIONS

6.1 Overview

Chapter 6 continues the research section with results from the analysis of the essay question section, the ranking section and the concept map section of the survey questionnaire. Results from the interview sessions are also included in this section.

6.2 Essay Question Analysis of Survey Questionnaire

Analytic induction (Znaniecki 1934, Denzin 1970) was used in analysing the essay questions. Procedures used were modified from LeCompte and Preissle (1993): (a) data were scanned to generate categories of phenomena; (b) relationships between these categories were sought; (c) summaries were written on the basis of data examined; (d) these were then refined by analysis and (e) negative, discrepant cases and anomalies were deliberately sought out.

There were three essay questions in the survey. 20 responses were collected from the respondents from each group, most of whom answered all three questions. The responses were then analysed according to how often a particular category appeared.

The first essay question for Group I, question 34, had to do with how students felt about learning a task through a VR environment and how it was useful to them. As shown in Figure 6-1, 40% of Group I students felt that using the VE allowed them to explore new ideas and have the ability to test these ideas. 30% felt that it made learning interesting for them. 25% of the students felt that the VE built their confidence in tackling the subject because they were able to try out their ideas and prove them in the system. This was also related to "Avoid Danger" (25%) because the VE provided a "safe" environment where they could test out their ideas without physically endangering themselves or damaging expensive equipment. They were also able to test the feasibility of the solutions first without loss of "face". 20% of the students felt that the VE system helped them understand the subject.

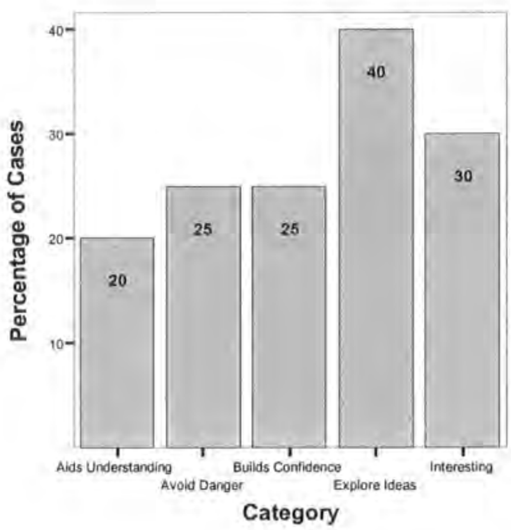


Figure 6-1: How students felt about learning in Group I (VR Environment)

On the other hand, when Group II students were asked how they felt about learning in a traditional environment, 30% of the students felt that the traditional method of learning was a trusted method that they had been used to since they were young. The learning was also orderly and systematic (25%) making them feel comfortable (20%). They also liked the face-to-face contact (20%) with their instructors and fellow students.

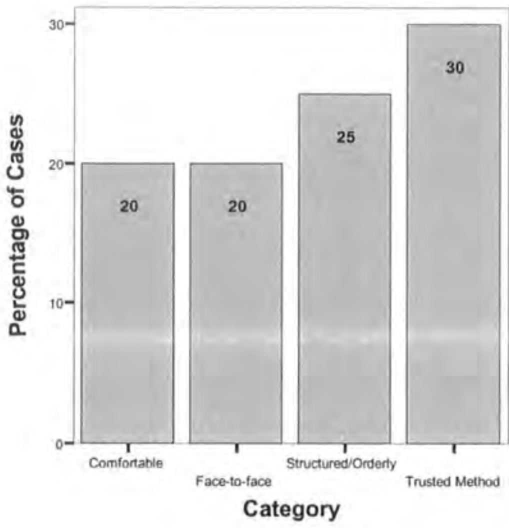


Figure 6-2: How students felt about learning in Group II (Traditional Environment)

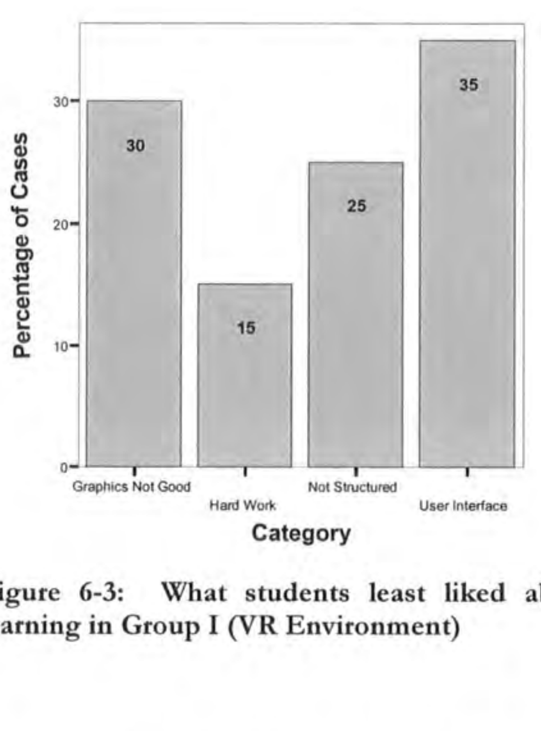


Figure 6-3: What students least liked about learning in Group I (VR Environment)

As shown in figure 6-3, students in Group I mostly disliked the user interface (35%) which they described as "difficult" and "complicated" to use. This was quite surprising as this finding contradicts question 19, where 70% of group I students indicated that they did not find difficulty in making use of the user interface. This required more in-depth study in the interview sessions. Graphics quality was also less than desired (30%), although this may have been a technical constraint. 25% of the students recorded that they had too much freedom in approaching the subject as the learning was not structured. This is related to the last category of complaints where 15% of the students said that learning was a much harder task compared to traditional means as students were required to put in more effort in their learning by having to actively think and interact with the environment.

Figure 6-4 shows the results obtained from Group II, the traditional group. When asked what they disliked most about learning in a traditional environment, two categories stood up equally at 35%. Concepts were said to be difficult to grasp at the beginning and the method was criticised as being too stifling. There was an inconsistency, as students in Group I feedback said that there was too much freedom in the learning. The next on the list was that there was too much memory work without understanding and the dislike of being told "what to do" at 20%. The last item at 15% was that there was difficulty in having to visualise what the concept was at the beginning of the lesson.

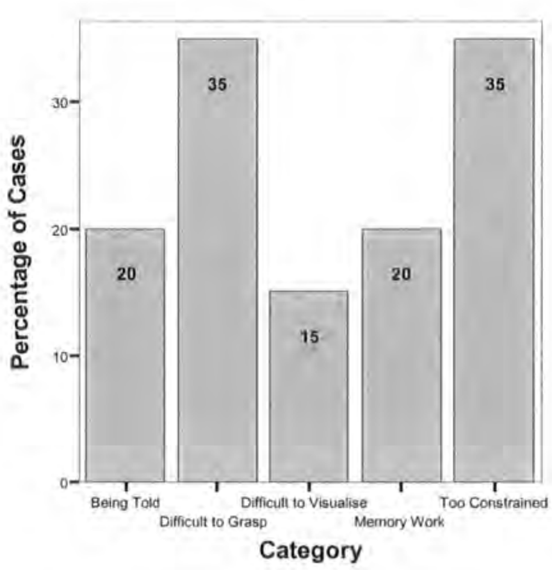


Figure 6-4: What students least liked about learning in Group II (Traditional Environment)

The last essay question in Group I, question 36, sought to discover what students felt were the best features in learning from a VR/VE environment. Figure 6-5 shows that students in Group I liked the VE for its ability to help them break down the goal into activities and test them separately (35%). The next two most preferred feature were the system's ability to provide immediate feedback for testing of activities and ideas and the visualisation feature allowing better understanding of concepts and ideas, at 30%. The last item at 25% was the system's ability to help students explore different ideas.

The last essay question in Group II, question 36, sought to discover what students felt were the best features in learning from a traditional environment. Figure 6-6 shows that students in Group II only liked two features of the traditional method. Most important to them was that the lessons were orderly and structured and that they feel comfortable in the class (65%). The face-to-face feature was the next most important at 40%. Students felt that they were able to get help in understanding the concepts.

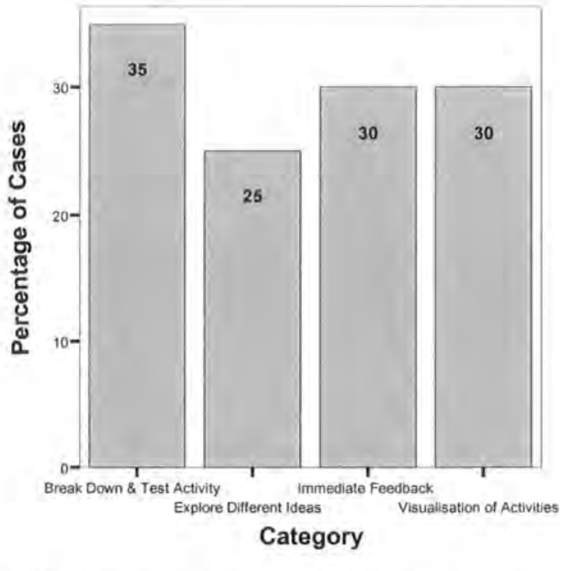


Figure 6-5: What students most liked about learning in Group I (VR Environment)

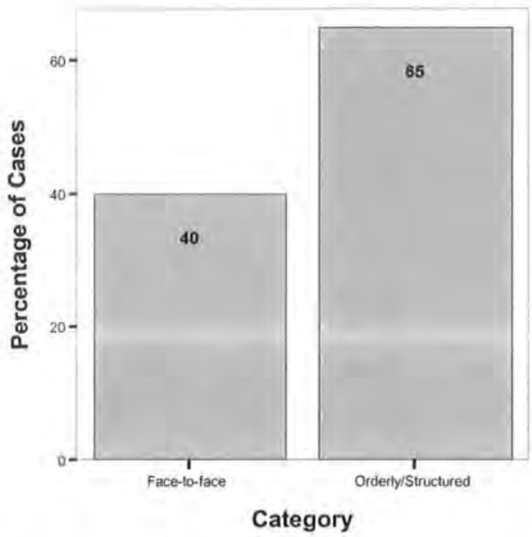


Figure 6-6: What students most liked about learning in Group II (Traditional Environment)

6.3 Ranking Analysis of Survey Questionnaire

Question 37 was the only question that asked the students in each group to rank, in order of importance, a number of given aspects of their learning. Students in Group I ranked six given aspects of VR which they felt were most important to their learning. Similarly, students in Group II ranked six given aspects of the traditional learning method.

The highest ranked item was allocated 6 marks and the lowest 1 mark. Summation of the allocated marks for each category was used to rank the various aspects.

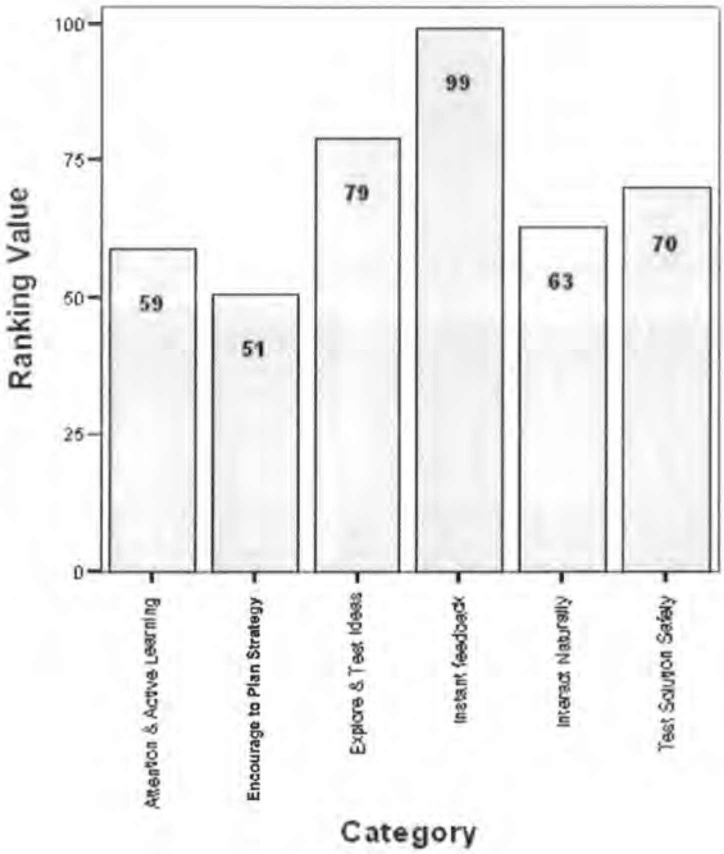


Figure 6-7: Student ranking of most helpful aspects of learning in Group I (VR Environment)

Figure 6-7 shows that Group I students ranked "Instant Feedback" as the most important aspect of learning in VR as the system was able to provide guidance as to whether the students' ideas were correct. This was closely related to "Explore and Test Ideas" and it was not surprising that this came up as the second ranked aspect. Basically, students had to generate their own intermediate steps as to completing the final goal and then test to see if their assumptions or strategies were correct. The system appeared to perform these functions very well and students could use these two aspects to generate ideas, test and then implement them. Close behind this was the ability to "Test Solutions Safely", "Interact Naturally", "Attention & Active Learning" and lastly, "Encourage to Plan Strategy". Students were concerned that their strategy would cause accidents and damage equipment.

In a real operation, instructors normally would encourage students to behave safely, hence clamping down on creative solutions, so this aspect was important to the student. The next preferred aspect was the ability of the system to mimic the actual operation of the equipment allowing students to interact with them naturally. The VE was also sufficiently interesting so as to foster attention and active learning by forcing students to work on solutions. This may be negative to students as shown in figure 6-3 of section 6.2, where 15% of the students indicated that it was "hard work" using the system. Encouraging students to strategise and

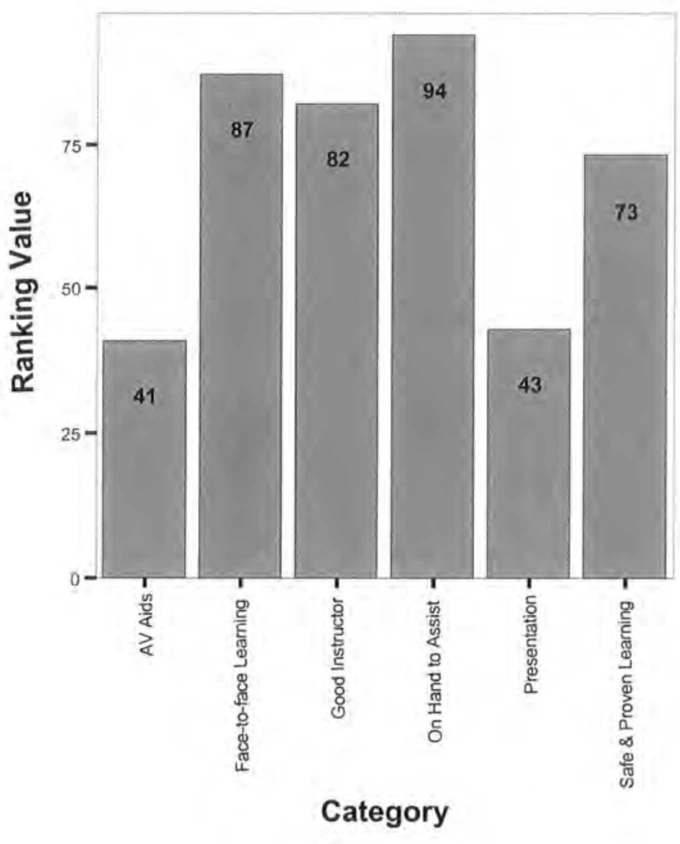


Figure 6-8: Student Ranking of Most Helpful Aspects of Learning in Group II (Traditional Environment)

to plan for the solution was ranked last. This is surprising because other factors seem to indicate that the system helped in promoting planning. Section 6.5.7 further illuminates this issue in the interviews.

In contrast, Group II students showed that they most preferred "On-Hand Assistance" (94%) provided by the instructor (Figure 6-8). The author felt that this was a rather negative aspect as it meant that the students were relying on the instructor's guidance to solve the problems instead of doing this themselves. This was closely related to the second and third ranked items, "Face-to-face Learning"(87%) and "Good Instructor" (82%). This again confirmed reliance on the instructor for problem solving. The next item was that the traditional system was a "Safe and Proven Learning" (73%) method of learning and students have been used to the system in which they felt safe. The last two items were related to the use of Presentation (43%) and Audio Visual Aids (41%) used by the instructor to help aid their understanding of the subject.

6.4 Concept Map Analysis of Survey Questionnaire

Drawings and diagrams are a kind of external representation, a cognitive tool developed to facilitate information processing (Donald 1991, Stenning & Oberlander 1995, Scaife & Rogers 1996). For a particular domain, sketches by students reflect their conceptualisation of reality, that "map" the critical elements of the domain. One aspect of drawing apparent to those studying drawings of children and adults, of novices and experts, was that drawings are naturally segmented into elements, that these elements are schematised, that they can be arranged spatially in endless ways (Kellog 1969, Goodnow 1977, van Sommers 1984). The order of drawing the elements of a sketch reveals the organisation, underlying the sketch. The organisation revealed could be at any of several levels, the hierarchical structure of knowledge, the sequence and the mental transformation. Winn et. al. (1991) and Poggenpohl & Winkler (1992) documented some elements of analysis of drawings, which were modified in this work.

The concept map analysis was carried out using analytic induction. A first pass scan was performed on the diagrams to generate categories of phenomena. This was followed by analysing the phenomena and the relationships and finally, teasing out the issues and anomalies from the diagrams. The concept map analysis was conducted using the information (sketches and notes) provided by students from the two groups in question 38.

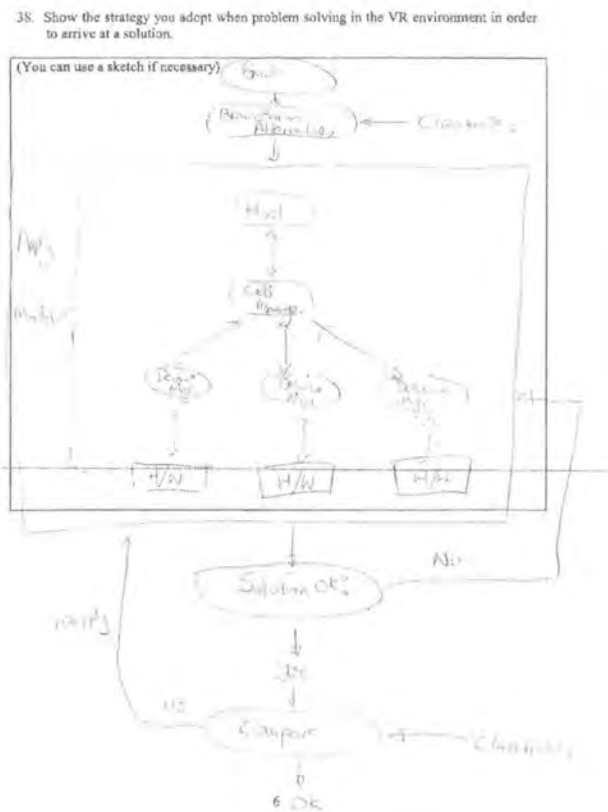
Students were asked to show the strategy they adopted to enable them to understand the topic and to solve learning problems in the subject area. In other words, this analysis sought to find out:

a). if there was a difference in strategies adopted by Group I and Group II, and

b). what kind of models were used by each group.

There were 16 valid respondents from Group I and 17 valid respondents from Group II. The other respondents left this question blank. Figure 6-9 shows examples of Group I respondents and Figure 6-10 shows examples from Group II respondents.

Whereas Group II students showed mostly linear models (94.12%) in their approach to learning, Group I students showed mostly models which were visually richer, more complex and had feedback loops (81.25%). This could be attributed to the emphasis on memorisation of facts and practice on isolated sub-skills in Group II. For example, every topic in Group II was taught as a complete unit by itself before moving to the next. Although chapters 1 and 2 of the syllabus gave an overview of components in the system, they were still, by definition, self-contained units. Group I students in using the VE, developed a model where they were able to see a more complete picture of the entire topic as a system with components that were dependent on each other, each learning unit having a specific relationship with each other. This was because the VE provided visualisation of the complete process. The VR system also encouraged the students to generate alternate solutions, which could then be tested individually, even at modular level. The solution finally selected would be based on students' experimentations. This was clearly reflected in the concept maps drawn by the students. Group I students adopted strategies that were more akin to problem solving (Andre 1986), for example, the characteristics of starting with a goal, followed by generation of alternative solutions, followed by analysis of the solutions, constantly referencing back to the objectives (feedback) and finally, comparison of analysis of results for a good solution.



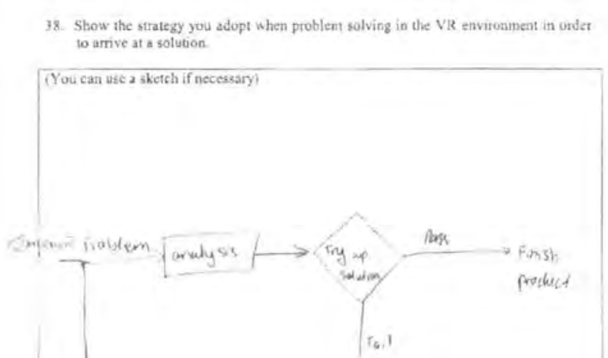


Figure 6-9: Samples of approach to problem solving from Group I

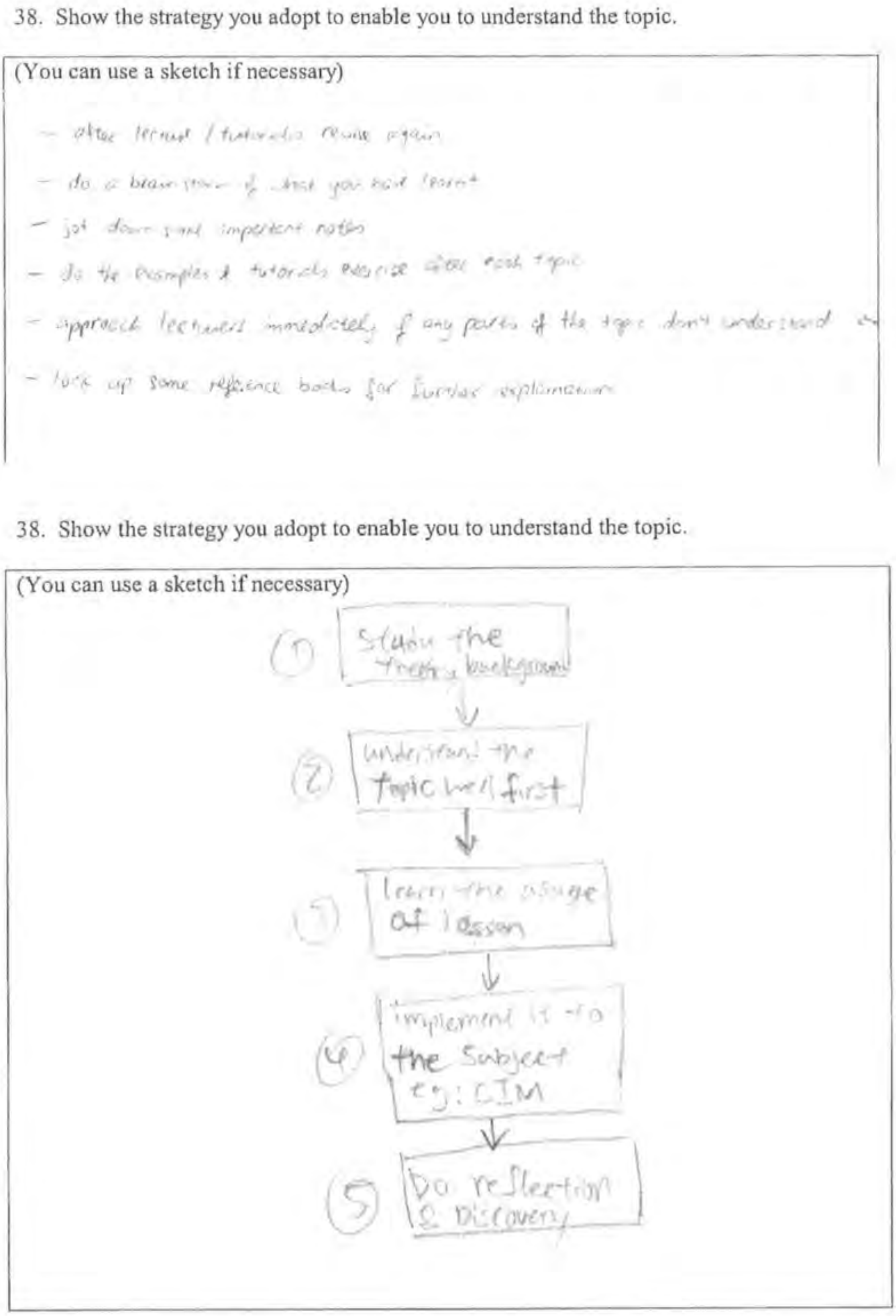


Figure 6-10: Samples of approach to problem solving from Group II

Group II students' diagrams were more linear; their strategies mostly comprised steps of analysis, planning, implementation, monitoring and modification. In analysis, students in

Group I basically identified aspects of the learning task (e.g. what, when, where), to understand the nature of the task (e.g. why), identify relevant personal characteristics (e.g. who), and identify potentially useful learning tactics (e.g. what).

Following analysis, planning involved students formulating a method to handle the task on hand. In implementation, the students employed one or more tactics aimed at enhancing memory and comprehension of the learning materials. They then monitored the degree to which the tactics had accomplished their aims. Although the words intimated feedback in their models (for example, monitor and modify), the diagrams drawn in figure 6-10 did not show that. This was probed in the interview. These phases were similar to those described in Snowman (1986). The following figures, 6-11 and 6-12 show the extent to which each group characteristic was present.

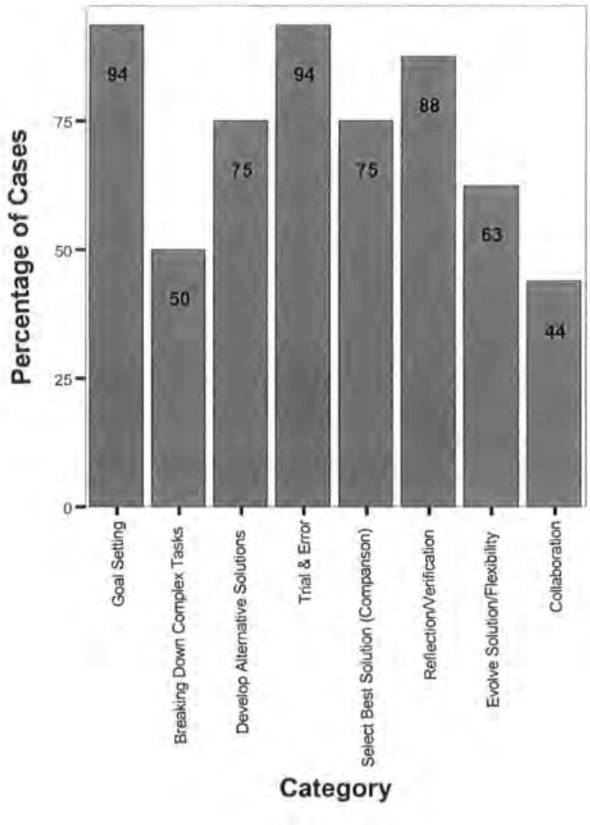


Figure 6-11: Concept Map Analysis of Group I Students

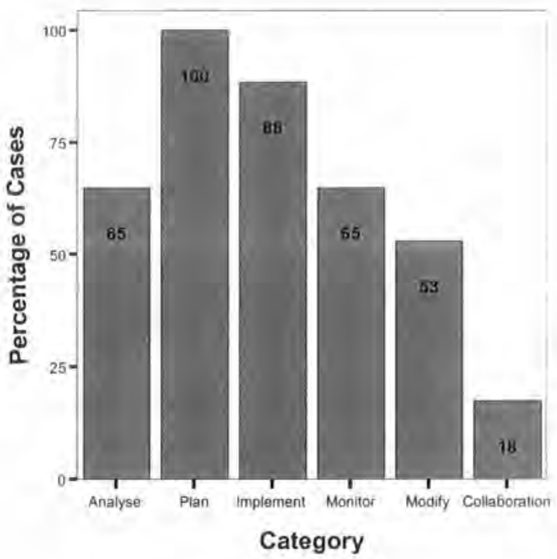


Figure 6-12: Concept Map Analysis of Group II Students

The majority of Group I students identified "goal setting" (94%) and "trial and error" (94%) in their diagrams. Students also constantly reflect and verify (88%), referencing back to the goals. At the same time, they developed alternative solutions (75%) and compared solutions (75%) with their coursemates. Collaboration among the students was 40%. What was not clear was what was discussed during these collaboration sessions. Again, this was further clarified in the interview sessions in section 6.5.4.

Group II students showed that they planned for their learning (100%), constantly executing their plan (implementation 88%), analysing (65%) and monitoring (65%) their implementation and modifying them (53%) where necessary. Collaboration among the students was 18% which was also reflected in section 5.3.15. The issue of low participation of collaboration in Group II was taken up in the interviews in section 6.5.4.

6.5 Interview Analysis

The interviews were conducted on the second week after the last day of the experiment. The one week in between was used for analysis of the data collected in the questionnaire. The main aim of the interview sessions was to provide a deeper understanding of the use of VR in augmenting the learning process by probing deeper into the students' comments in the survey questionnaire. Data from students, whose group and individual responses were found to be ambiguous or interesting, were probed individually for explanations. This was similar to what Kerlinger (1970) suggested where the interview was used in conjunction with other research methods to follow up on unexpected results, validate other methods and to delve deeper into the motivations of the respondents and their reasons for responding as they did.

The interviews were conducted by the author and it is acknowledged this could have affected the responses of students in both groups as well as interpretations of these responses. Possible bias was minimised through using a structured and standardised interview questionnaire (see Table 6-1). The interviewee was also briefed on the relevant reasons for the research and why the interview as conducted. Throughout the interview, the author also sought to avoid ambiguous and leading questions put to the interviewee by planning and designing the questions ahead.

Many of the Group I students, in addition to using words to describe their experiences, used their hands in the same way that they had while in the virtual environment. This indicated a somatic memory that is not described in the text-based data, but is well worth mentioning (Kraft & Sakofs 1989).

The following questions shown in table 5-3 were identified and developed during the analysis of the survey questionnaires. Four students from each group were selected for the interview sessions. The first question was used to put the students at ease for subsequent questions. This involved identifying a question that was reasonably comfortable for the students to answer.

Issues to Clarify	Group I Question Guide	Group II Question Guide
Comfortable question on learning To confirm reasons why Group I students indicated they learn better in a VE. (eg. Trial & error, safe, planning, motivation, etc.)	Why did you say that you learn better in the Virtual Environment rather than through communications with friends and instructors? How do you learn better? Were you motivated to learn? Why?	Why did you say that you prefer to learn by communicating with friends and instructors than by using a VE? Throughout the process, were you motivated? Why?
Learning method preference Group I students indicated 0% "Strongly Agree" and 80% "Agree" in question 14, a question asking students if they prefer learning by interacting with the VE. What were the reasons for the low percentage in the "Strongly Agree" component? (eg. Effort needed by students to use the system)	In question 14, a question on whether you prefer to learn by directly interacting with VEs, what was the reason for not indicating a "Strongly Agree" position?	-
Independent Learning In question 20, Group I students indicated that they were able to solve problems with practically no help at the end (75%). Group II students only indicated 25%. What was the reason for the disparity?	In question 20, you indicated that you were able to solve problems with practically no help in the end. Why was this so?	In question 20, you indicated that you were not able to solve problems without help in the end. Why was this so?
Assimilation In questions 22, 23 and 32, Group I students indicated that they were able to assimilate more information faster. Why was this so? It was also strange the Group II students indicated in Question 32 that they also think that they could have learnt more from a VE system (60%).	In questions 22, 23 and 32, you indicated that you were able to assimilate more information faster. What made you say that you were able to learn more and also at a faster rate using the VE?	What made you indicate in question 32 that you would be able to learn more from a VE?
Collaboration In questions 26 and 27, 100% of Group I students indicated that they collaborated with each other. What did they do and how did they collaborate? Group II students indicated that they collaborated (70%) in both these questions but there was little evidence of this shown in the concept map (18%). What is the cause of this disparity?	In questions 26 and 27, you indicated that you discussed the solution with your coursemates and were able to arrive at solutions by working together. What did you actually do in your discussions?	In questions 26 and 27, you indicated that you collaborated with your classmates, but in the concept map, there was little evidence of this. Can you help to explain this?
Perceived ease of learning In questions 19 and 21, Group I students indicated that they found that the user interface would not be an obstacle to learning (70%) and it was easy to arrive at a solution (100%). However, in the essay question 35, the user interface was listed as the least like feature (35%). What was the cause of this contradiction Also, there were factors holding back 30% of students in using VR due to ease of learning. A small group of Group II students	You indicated that the user interface would not be an obstacle to learning in question 19 and it was easy to arrive at a solution in question 21. Yet in question 35, the user interface was listed as the least liked feature. Is there a reason for this indication?	You indicated that the user interface would not be an obstacle to learning in question 19 and VR would not be difficult and painful to use in question 33. However, you felt that it was difficult to use it to arrive at a solution in question 21. What was the reason for not being able to arrive at a solution?

indicated in question 19 that they thought that the new user interface in VR would not be an obstacle (10%), and in question 33, learning using VR would not be difficult and painful (55%). Yet in question 21, they indicated that it would be difficult to arrive at a solution using VR (10%). If the system itself was felt to be moderately easy to use, why was it felt that they could not arrive at a solution?		
Aspects of Learning In essay question 35, there appeared to be a controversy. 25% of students in Group I complained that the VR/VE system was not structured and there was too much freedom whereas students in Group II complained that the traditional learning method was too constraining (35%). What does this feedback indicate?	You mentioned in question 35 that the VR/VE system was not structured. Can you further elaborate on this? Can you also suggest how to improve the system?	You mentioned in question 35 that the traditional system of learning was too stifling. Can you further elaborate on this? Can you also suggest how to make learning more interesting?
Planning In question 37, Planning was seen as the least important aspect of learning in VR by Group I students. This was a concern as this is a most important step in problem solving. Why did students rank this aspect last?	In question 37, feedback on ranking the important aspects of learning in VR, you ranked planning last. What was the reason for this?	-
Feedback Loop In question 38, Group II students intimated that there were feedback (monitor 65% occurrence, modify 53% occurrence) in their model of learning but compared to the diagrams drawn by Group I students, these were not clearly reflected in their diagrams. Why was this so?	-	You indicated elements of feedback (e.g. Monitor and modify) in words but your diagram does not reflect this feedback. Can you help to explain this?

Table 6-1: Questions Identified for Interview Sessions

Also, interviewees were chosen such that there was an alternate perspective in each question. For example, in Group I, amongst those selected, there would be a student who had said that he did not learn better in VE compared to a majority that did. A sample transcript of the interview is found in Appendix H.

6.5.1 Learning Method Preference

In Group I, students felt that they learned better in VE because it gave the learning experience an added dimension by providing interactive visualisation, the ability to view and test their ideas through exploration without fear of being criticised or damaging equipment. Also, they felt that their instructor might not interpret their questions correctly. The VE also provided a good platform for collaboration/discussion on the problem because it could be used to represent exactly what the problem was. It also allowed the students an independent learning experience instead of being told "how to do it" as commented by a number of students in Group I. By allowing students to learn from the system, students also learnt how not to be dependent on their instructor for information. Regarding motivation, one of the students said that because of the interactive nature of VEs, lessons learnt were easily recalled and retained longer. This was because the VE captured the attention of the student, the VE context was relevant, the system helped him to gain confidence in the subject and finally, he was very satisfied with the final solution attained. Keller (1983) and Keller & Suziki (1988) talked about these important factors in their work on building intrinsically motivating instructional model. Also, in the word of the Group I students, they "don't need to be so careful" in their exploration, giving them confidence to explore their ideas. Students thus felt "safe" to explore ideas that they normally would not have, due to constraints of endangering their own safety or damaging expensive equipment. In the process of this freedom, they were able to come up with many viable solutions. In question 14, a question on whether students prefer to learn by directly interacting with VEs, Group 1 students did not choose "Strongly Agree" because there were still some reservations due to the fact that the training method was not as established as the traditional method. Students also felt the user interface of the VE needed getting used to as it was not easy to use. Students in Group I who felt that they did not learn better in VE said that it was due to the different levels of complexity in the subject. Some chapters were less complex and it was felt that the traditional method served better in communicating the idea. This was because they had to perform a number of tasks to get the information rather than getting it straight from the instructor.

Group II students preferred to communicate with friends and instructors because they felt that face-to-face communication was easier and faster. Also, they felt "safe" as they were used to the more established method. Others felt that they were not very comfortable dealing with computers and they needed a "person who can guide me through". Alternate views in this group (who have the opinion that VE was a better learning environment) gave reasons such as being given the opportunity to learn at their own pace, allowing a process to be repeated until they understood, thus allowing closer and more detailed examination of the subject. Group II students also said that talking to classmates and instructors "would often act as a muse" and would serve as a motivating factor by creating new ideas with which could be explored further.

6.5.2 Independent Learning

Group I and II students were asked if they were able to solve problems with "practically no help" in the end. The high percentage of difference (75% in Group I vs 25% in Group II) in the 2 groups was a concern.

The students in Group I who said that they were able to solve problems gave reasons such as "a matter of getting used" to the environment at the beginning, a matter of learning from "exploring" the environment which although time-consuming, yielded reinforced understanding of the topic. The VE appeared to inculcate self-regulated learning behaviour in this group as they were able to assume personal responsibility and control of their acquisition of knowledge and skill (Zimmerman 1990). The life-like interactive simulation also played a part in the learning process. The student who said she was unable to solve problems using the VE gave reasons such as the user interface being "difficult" to use and need "getting used to".

Methods used by students in Group II who said they were not able to solve problems included seeking the instructor's guidance or their friends' help "face-to-face". They also referred to textbooks. This group of students felt that this was a faster way of getting the appropriate answers than finding them out for themselves. The student who said he was able to solve problems commented during the interview that the "direct exchange" in the lectures and tutorials was useful in ensuring that he did not miss out on important points that might have got left out if he had had to explore the VE himself.

The interviews showed that Group II students were over-dependent on their instructors and also on their more capable friends. Although they were able to solve problems at the end, they needed help from their instructors and peers. Group I students were more independent as they took to learning by exploring and trying out ideas although it was perhaps more "difficult", in the sense that the information had to be discovered by exploring the VE. Students also took some time to get used to the new user interface in the VE. This hurdle might perhaps have proved difficult for students who had less experience or who were less computers-oriented. However, the reason for the success rate in Group I being higher could be due to the fact that the subject under study was an engineering subject and the students were engineering students.

6.5.3 Assimilation

Students in Group I indicated that they were able to assimilate more and faster compared to Group II students. Students in Group II suggested that they could have learned more from a VE (60%). This section describes the reasons for these indications by the students.

Group I students replied that they were able to assimilate more and faster due to the following reasons: interactive visualisation, a life-like simulation and the ability of the VE to allow students to see the instant feedback on students' exploratory ideas. The simulated experience in the VE led to a better understanding and allowed students to reflect on what they had done. They were also able to see the subject as a whole rather than see it in fragmented topics. The student who said he assimilated less and was slower had experienced difficulties with the user interface and was spending more time on that than on the course.

Group II students felt that extra "information outside the syllabus" could be learned from being in the VE compared to just learning from course materials. They also felt that visualisation in the VE would lead to faster and stronger understanding of the subject as well as making the subject more interesting.

6.5.4 Collaboration

Group I students collaborated (100%) with each other. They indicated that although a VE is often thought of, as a "lone interaction", it in fact provided a good mechanism for collaborative discussions. This was because the 3D environment allowed ideas to be communicated easily on a common platform through visualisation. This made it easy to see problems and solve them. Also, as a result of using the 3D environment in the discussion, more ideas were generated.

Group II students also indicated that they collaborated (70%) with each other. They collaborated by discussing problems with their classmates and in study groups with peer teaching. One reason why there was less collaboration compared to Group I was attributed to the difficulty of communicating complex ideas without tools such as the 3D environment. When queried, students in Group II replied that they had thought about collaboration when they were writing down their concept maps in question 38, using terms such as "concept strengthening", exchanging ideas and so on. It was noted that the maps shown by Group II students were less visual (figure 6-10).

6.5.5 Perceived Ease of Learning

There appeared to be a conflict when students in both groups answered questions 19, 21 and 35. In Group I, students said they found that operating the user interface was not difficult, that it was easy to use it to arrive at a solution but they also listed the user interface as a least-liked feature in the learning process. In Group II, a small minority of students indicated that they felt that the VE's user interface would not be an obstacle to learning, that they would not have difficulties using the VE system, yet indicated that it would be difficult to solve problems using the VR system.

During the interview, it was discovered that Group I students mainly perceived operating the user interface and using the VR system to arrive at solutions as different items. They felt that for a beginner, the user interface was not easy to operate, as it was a new method - one that they were not accustomed to. However, if effort was spent to get used to its operation, then using it to solve problems was perceived as easy. This also answered the question why 30% of Group I students still perceived that the system was not easy to use.

The main group of Group II students perceived the same problems. They thought that they "have to overcome the barrier of using the user interface in VR". This might have proved a difficult hurdle for them. But, having only seen VR applications (experienced through the various talks and visits during the first and second years of their course), and with no experience in using them, the percentage was lower compared to Group I (10%). On the other hand, a minority group of students had a different perspective. An interview with a student from this group gave the following illumination. He felt that as engineering students, there should be no problem in students using the VE as it is a software application and students learn to use new software very frequently throughout the course, often on their own. However, using the VE system as a learning tool to solve problems involves analysis and he strongly doubted if a VR system could be used to support this. He also doubted whether using the system is different from applying it to a real-life problem.

6.5.6 Aspects of Learning

In the survey, Group I students complained that as a learning tool, the VR/VE system was too unstructured whereas Group II students complained that the traditional method was too constraining. This was clarified in the interview session.

In Group I, the main reason for the VR/VE being unstructured was the fact that students could start from several locations to work on the problem. The students could also "jump step" and work on other parts of the solution first. However, when given too many options, students did not know where to start. A counter-argument was provided by another student. He said that the system itself mimicked the real world, where problems in the factory were unstructured. He felt that there must be flexibility to solve problems because that is what the real world is like.

Group II students suggested that they took too long to get a concept from lessons by progressing sequentially. The structured system made learning slow and they had a hard time memorizing facts without understanding them.

One student gave a good solution to this issue. If a person was familiar with the topic, he could afford to explore to get more detailed information. If a person had less knowledge of the subject, then he would prefer to be guided. A student also suggested having a good guideline to explain what they were going to do and also the end result so that students could have an idea of how to start. So a good compromise would be for instructors to help start the process by working on the system itself with students in the beginning. Another student suggested making the system more friendly by using guided instructions in the VE itself, for example, using some sign to indicate that the item was next to be used. VR/VE should not be limited to the laboratories. A Group II student suggested bringing VR/VE to the lectures where concepts and problems would then be clearly demonstrated using the VE.

6.5.7 Planning

It was discovered that Group I students were not identifying planning as an important aspect in their learning. This trend was shown in the ranking exercise in question 37. Most students rated planning as one of the least important aspects in their learning in Group I. This was a concern.

The reasons emerged during the interview sessions: "There's always this mentality that if you do it wrongly, never mind, because you can always go back to do it again … rather than planning, you're doing a hit-and-miss kind of thing, once you hit, then the next time you follow this step …"; " You can review it, and if it fails, it doesn't matter". A totally different scenario was provided by another student who ranked planning as fourth out of six aspects of learning. She said that she worked by exploring the boundaries before making plans as she needed to know what could be done first. Hence, planning was less important to her.

It was noted that most students had placed planning in their conceptual map. Hence planning was clearly part of their process. Given the feedback by the students, there was a strong possibility that a VE environment could lead to students not bothering to plan or placing planning as less important in the scheme of problem solving and learning because they would be able to "test" out the solution. On the other hand, it could also be advantageous to students as it encouraged them to solve problems that were not clearly defined, or constantly evolving. By learning to explore the boundaries and performing a series of tests, they could solve such problems as they went along.

6.5.8 Feedback

In question 38, Group II students intimated that there was feedback (monitor 65%, modify 53%) in their model of learning but these were not clearly reflected in their diagrams compared with those of Group I students.

Group II students said that they had the image of the feedback loop in their mind while they were working but they did not translate that into diagrams. Students only put their thoughts in letters and sentences in question 38, which did not show up as feedback loops (diagram of continually modifying a solution until it reaches an acceptable condition). This showed that Group II students did in fact modify and develop their solutions.

6.6 Summary of Findings

The independent t-test comparing overall results obtained during the objective test showed that there was no significant difference in the mean score obtained by students undergoing

VR augmentation (Group I) and the traditional learning group (Group II). However, Group I results were consistently higher than Group II in both analysis of the overall test paper result as well as analysis of individual questions in the paper. Independent t-tests performed on individual questions in the test also revealed that there was a significant difference in the question involving problem solving.

An analysis of the 33 Likert Scale questions in the questionnaire using frequency distribution and t-test revealed the following differences in learning between the VR augmentation group (Group I) and the Traditional group (Group II).

- Students in Group I showed more involvement in planning, in the areas of setting intermediate goals, breaking goals into activities and modifying and developing their answers along the way as they learn more. There were significant differences in the scores from Group I and II in these areas.

- Students in Group I showed more evidence of being able to identify and set goals and sub-goals. The t-test used showed significant differences in the scores from Groups I and II.

- Students in Group I were more able to demonstrate understanding by recognising tasks and activities in learning, by being able to mentally visualise the activities and by modifying and developing their answers along the way as they learn more. Analysis using t-test showed that there were significant differences in the scores in these aspects of improving understanding.

- Students in Group I were more able to explore and try out new ideas, locate and correct mistakes, as they were able to conduct experiments in the VE, thus allowing them to have instant feedback and to test each activity before moving to the next in a logical manner. These factors where significant when the differences in the means of Group I and II students were compared using t-test.

- Students in Group I showed more instances of being able to look back and reflect on what they have done in their learning. However, the difference in the two groups was not statistically significant in the t-test.

- Students in Group I showed that they were able to form abstraction by generalising approaches learned in the VE to solve other problems. The t-test for comparing the difference in means was significant.

- Students in Group I showed that they were more actively involved in their learning. The factors analysed show significant differences between Groups I and II.

- Students in Group I showed that they were able to show divergent thinking by trying out different ideas and approaches to solving the same problem. The result in the analysis was statistically significant.

- Students in Group I showed that they were able to show convergent thinking by modifying and developing solutions as they get more information. The results in the analysis were statistically significant.

- The majority of Group I students preferred to get information by directly interacting with the computer whilst Group II students preferred face-to-face contact. This could be explained by Festinger's Theory of Dissonance (Festinger 1957). This will be discussed in the next chapter, section 7.7.2. Statistically, no significant difference was shown when the results were analysed.

- Group I students felt safe in the VE because they were able to explore ideas freely without fear of damaging expensive equipment or endangering themselves. Group II students felt safe because they were using an established mode of learning. It was shown that there was a significant difference in the level of safety felt by the students in both Groups.

- Group I students were more independent in their learning as they gradually grew less dependent on their instructors and were able to solve problems on their own compared to Group II students. Again the analysis showed that there was a significant difference in the level of independence felt by the students.

- Group I students assimilated more information faster due to the interactivity provided by the VE. In terms of learning faster and absorbing more information, Group I scores indicated significant differences when compared to Group II. However, when both groups of students were asked if they learned more using VR/VE, t-test analysis showed that there was no significant difference. Again, this could be explained in terms of Festinger's Theory of Dissonance, which will be discussed in section 7.7.2.

- Group I students showed they were able to collaborate more. When students were asked if they discussed the problem with their course-mates, Group I students showed more collaboration than Group II students. Both groups believed that they collaborated in the course of learning. This will be discussed in the section 7.7.2 in the light of Festinger's theory. The scores were significant in favour of Group I when students were asked if they were able to reach a good solution after discussion. Both groups believed they collaborated, but Group I students were more positive that they got a good solution out of the collaboration.

- Group I students felt that they were able to overcome the barrier of technology in using the VE as part of their training. All factors involved showed that there was a significant difference in the scores when comparing Group I and II students.

- Group I students felt that they enjoyed their lessons more. This was observed when the frequency distribution was analysed but statistically, the t-test showed that the difference was not significant. Both groups felt that they enjoyed their lessons. This will be discussed in the light of Festinger's theory in section 7.7.2.

- Finally, Group I students were more able to solve problems by planning, being independent and also collaborating. The items analysed showed statistical significance.

The essay questions in the questionnaire yielded the following information:

Group I students felt that the VE helped them to explore new ideas by allowing them to come up with solutions and by giving immediate feedback. The VE was also an interesting and enjoyable way to learn. It helped to build confidence, encouraging students to be independent. It also provided a safe environment for testing out their ideas, in terms of physical safety as well as safety related to "face". Group II students felt that the traditional method of learning was one they were used to and it was orderly and systematic. They were comfortable with the system and they appreciated the face-to-face contact with their instructors and fellow students.

The majority of Group I students disliked the user interface because they felt that it was difficult to use. Also, the graphics in the VE were not as good as they had expected. The unstructured way of learning as well as the "hard work" involved in mining information from the VE was unpopular. Group II students felt that the traditional system was too constraining and concepts, especially complex ones, were difficult to grasp using existing methods. They also disliked "being told" what to do as well as the memory work involved in the lessons.

The majority of Group I students liked the feature of being able to break down and test each individual activity in the VE, the immediate feedback provided when testing ideas, the visualisation and the ability to explore features in the VE. Group II students liked the orderly and structured lesson with face-to-face contact.

In the ranking exercise, Group I students ranked "instant feedback" as the most helpful feature in learning in VE. The least important was "encourage and plan strategy". In Group II, students ranked "on hand to assist" as being the most important feature in traditional learning environment and the use of "AV aids" least important.

In the concept map, it was noted that the diagrams or maps put up by Group I students were more extensive and visual compared to Group II students. Group II students mostly showed linear models in their diagrams. This could be due to strategic differences in their learning or problem solving. For example, it could be seen that Group I students adopted strategies that were more related to trying out ideas while Group II students involved a pre-planned path.

In the interviews, the following observations were collected:

- Group I students felt that they learned better in VE because it gave the learning experience an added dimension by providing interactive visualisation, the ability to view and test ideas through exploration and "safety". Brown (1983) called this experience "learning by doing". Factors in the VE, contributing to intrinsic motivation, such as the presence of attention holding elements, relevant concepts and practise elements, confidence enhancing elements, and giving the users a sense of satisfaction were present. These important elements were part of the tools used by Keller (1983) in his work on building motivational instructional models. Group II students preferred to communicate with peers and instructors because it was easier and faster. Others were not comfortable in dealing with computers.

- Students in Group II appeared to be less independent than Group I students when it came to solving problems. Group I students exhibited self-regulated learning behaviour.

- Group I students assimilated more information faster due to features provided by the VE. Students were able to have a more "holistic" view of the entire topic instead of only fragmented views. However, some students were not able to overcome the barrier of operating the user interface. Group II students also felt that the VE system could offer them new learning experience and information that was "outside the syllabus" if they were to use it.

- Learning in VE was not a "lone interaction" because it in fact helped to provide a good way of communication with peers in a collaboration. Ideas and solution could be demonstrated and tested out quickly. Collaboration was less obvious in Group II.

- Group I students perceived operating the user interface and learning in the VE as different items. The user interface was difficult to use in the beginning, but after getting through the barrier, it was easy to use it to get solutions from the VE.

- Group I students perceived the VE as unstructured and they had to mine it to get the information they needed. They also had problems starting the process of learning as there were too many options. Group II students perceived the traditional learning method as too stifling and structured. It contributed to slowing down their learning process.

- Planning was not viewed as an important aspect in learning in VE because the environment encouraged exploration and trial and test. The mentality that there is always another way, another chance to try it again led students to neglect the planning aspect.

- Group II students do collaborate and learn via feedback from peers and instructors. But these were not highlighted as actual diagrams in the concept maps. Instead they were embedded in texts in the diagrams.

PART IV

CONCLUSION

7. CONCLUDING DISCUSSION

7.1 Discussion Overview

Given that the ability to understand abstract and complex information is increasingly important in research, industry and education, learning environments that support these skills are in growing demand. One of these new learning environments that rely on visualisation and engaged interaction is based on VR. A critical step towards achieving an informed design of VR learning environments is the investigation of the interplay among VR features and other factors such as the learning experience and the interaction experience. Understanding how these factors work together to shape learning will help in understanding how to target learning and visualisation problems with the appropriate features and to maximise the benefits of this emerging technology.

In this chapter, findings from chapters 5 and 6 are reviewed and discussed, linking back to literature from chapters 2 and 3. The organisation of this chapter utilises the research questions identified earlier in chapter 4 as a basis for discussion. The chapter ends by suggesting further research areas and describing pertinent points relevant to anyone considering virtual environment in the classroom.

7.2 Did VR technology help improve students' learning processes when compared to traditional classroom methods? How did it help?

Despite conforming to pre-conditions of implementing a virtual environment for learning identified in chapters 2 and 4, the independent t-test showed that there was no significant difference in the mean score obtained by students undergoing VR augmentation (Group I) and the traditional learning group (Group II). Analysis of individual question scores in the test revealed that while there was no significant difference in scores between the two groups for questions relating to memory, differentiation and application of formulae, there was a significant difference in the score related to problem solving. The ES value (0.68) observed in the problem solving question showed that the use of VR augmentation in this experiment led to a higher than average chance of improving engineering problem solving skills. It should also be highlighted that for every question, the mean score of the VR augmentation group was higher than the traditional group, though it should be noted that the VR group had a slightly higher pre-test score.

These observations can be interpreted in the light of the results obtained from the concept maps drawn by the students. The maps drawn showed the strategy employed by the students in solving problems in the domain area. Group I students seemed to be clearer in their approach, showing graphically how they broke a problem into smaller components for testing. There were also the elements of comparing alternatives and iteration or refining the solution. From the concept maps, approaches by Group II students appear to be mostly linear. The interview sessions showed that Group I students felt that they learned better because of the added dimension of the interactive visualisation, allowing them to test their ideas and giving immediate feedback. They were able to step back from the problem to visualise it in a more "holistic" manner, allowing them to "see" a causal relationship between their individual actions and the entire system. The system also allowed them to think in both divergent and convergent manner. These findings seem to indicate that the VE helped students to exhibit useful problem-solving behaviour (See section 7.7). The broader implications will be that students may form intrinsic learning abilities, enabling them to see connections across the curriculum.

Students in Group I were involved in planning, in the areas of setting intermediate goals, breaking goals into activities and modifying their solutions along the way. However, the survey also showed that they considered the planning aspects in VE as least important in their learning. Interviews showed that a possible reason was that students could test out different alternatives until they found one that worked. Although this mechanism could be of great help to students who are able to develop alternate hypothesis for testing, some students may be using this mechanism on a "trial and error" basis.

There is substantial evidence linking the quality of metacognitive processing with development of knowledge structures (Butterfield, Albertson, & Johnston, 1993). Metacognitive components such as planning, self-monitoring, evaluation and reflection are assumed to be indicators of how closely students approximate the behaviour of experts. One externally visible indicator of metacognition is the students' reliance on feedback and support while using an instructional program, i.e. in the virtual world.

Although students in Group I claimed that they were able to assimilate more information and learned faster, there was a learning curve in terms of utilising the user interface in the VE for learning. This and the fact that the VE is unstructured may lead to further discouraging the students in their engagement with the VE. This was pointed out clearly in the interview sessions. However, once the students got over the barrier of the new method of working, they were able to engage fully in their learning. One student, however suggested that the VE system needs to have more "cues" than it currently has. This would help, he said, to ease the burden of overcoming the learning curve. This is in line with what literature suggests, that the cueing mechanism is a top priority, which is sometimes forgotten by instructional designers (Reed 1985, Mayer & Anderson 1991, Rieber 1991, Gagné, Briggs & Wager 1992, Luetner 1993).

From the Likert scale section of the survey questionnaire, several learner characteristics stood out with their high ES value. These indicated that students thought they had a high impact in helping them to learn. These factors were again validated in the essay and ranking questions of the survey..

Planning skills:

- Setting intermediate goals
- Breaking goals into activities
- Allowing gradual development of domain concepts

Thinking skills:

- Able to abstract relevant or critical information, leading to generalised approaches to solving problems.

- Convergent thinking. Divergent thinking was also significant but the ES value was medium.

- Better assimilation of information due to effort spent mining for the knowledge. This is very similar to Bruner's concept of "learning by doing" (Bruner 1990) and the theory of constructivism (section 3.1.3).

- VE provides a good mechanism for encouraging students to think about problem solving approaches.

Independence:

- Gradually learn to be self sufficient by being less dependent on the instructor

- Able to successfully accomplish tasks without help

Findings from the essay questions showed that students also thought that the ability to explore the VE, the novelty effect and building of confidence were important elements in encouraging them to be engaged in their learning.

As pointed out earlier in chapter 3, Dick's (1992) concern regarding the gap between the schema of some students and the tools they are provided with (in this case, the VE), was shown to be valid as there were students who pointed out that there was a "barrier" in learning to use the tool. Perkin's (1992b) reply to this view was also seen as valid as the students did learn to overcome this "barrier" and to finally use the VE for their learning. It was noted that the relevant support and cues were provided with the VE to help the students in this quest, again utilising the findings from the literature review. In this case, a BIG, rather than a WIG constructivist model of learning was used, as the treatment the students were subjected to included lecture/tutorial sessions to help them with the groundings of concepts. It should be noted as well that these students were not novices, having had a 2-year foundation in the domain area.

7.3 Which aspects of using VR assisted the learning process?

Features in VR in the experiment that were shown to have assisted in the learning process include:

Visualisation:

- Helped to recognise tasks & activities
- Helped to visualise activities mentally
- Helped to see activities as part of a "whole" rather than independently.

Trial & Feedback (this aspect was constantly ranked highly in the essay and ranking questions):

- Helped to test activity before moving to the next
- Helped to locate mistakes and to make corrections
- Allow exploration to try out different ideas
- Allow instant feedback

Engagement:

- Captured attention and foster active involvement
- Lessons became a reality in the environment
- Understanding clearly how the actual system was operated from the VE

Safety:

- Allow ideas to be tested on the computer

Visual perception and engagement were shown to be important factors in the learning environment, partially verifying literature findings in section 3.2 (Levin & Kaplan 1972, Sternberg & Davidson 1983, Pavio 1991, Laurel 1991, Kearsley & Shneiderman 1999 to name but a few). Furthermore, the interactional ability in the VE for students to explore the environment and to test their "hunch" was an important consideration in their learning. These characteristics allowed students to construct knowledge directly rather than through abstract and often difficult symbol systems. The idea of "safety" also appealed to the students.

7.4 Were students motivated by the VR experience? How were they motivated?

Literature reveals that two important factors must be present for motivation to take place. An individual must see benefits in initiating and sustaining a task. Sources of motivation include curiosity, perceived relevance of task and self-efficacy. Continuing to sustain motivation often requires satisfaction of expectancies in the current learning episodes. Motivation appears to be enhanced when learners attribute their successes to their own efforts and effective learning strategies.

In this research, VR was shown to stimulate both perceptual and inquiry arousal (section 6.5.1) resulting in an active engagement between the students and the virtual environment (section 5.3.8). Learning task relevance was demonstrated in that students were able to set relevant goals in the subjects (both explicit and proximal goals (section 5.3.1)), and to be able to invoke alternate scenarios and test them, indicating a "mastery-oriented" goal orientation. Group I learners were also more independent (section 5.3.13), as they gradually became more confident in their efficacy and outcome expectations. Papert (1980) has shown that increasing control may enhance feelings of self-efficacy and assist learners in taking independent responsibilities for their own learning and behaviour. This in turn, leads to a virtuous cycle where their expectancies were satisfied and successes attributed to their own efforts and effective learning strategies, in turn leading to a sustained level of motivation.

However, it should be noted that some students might not be able to make effective use of learner control. For example, Fry (1972) showed that the use of learner control actually increased learning when the students were of high aptitude or exhibited high level of inquiry about the content area. He suggests that subjects who have higher ability in the content area are more able to make judgements about their progress and need for instruction, which ultimately, resulted in greater learning. Ausubel (1978) also argued that a subject's prior familiarity might provide a necessary anchor for him or her to make decisions in a new learning situation. This again boils down to prior knowledge of the learner.

7.5 Which aspects of using VR motivated the students?

In contrast to literature findings (for example Byrne 1993, Lewis 1994 and Osberg 1995), enjoyment was not found to be significant in the Likert scale portion of the questionnaire, although the mean obtained in Group I was higher. Although Lewis carried out his experiment on children, Osberg's subjects were 16 to 18 year olds whose age group were close to this experimental group of 18 to 20 year olds. However, Osberg noted that there was a maturation effect and the students' enthusiasm was noticeably less than in primary school students. This could be due to the fact that older students were more able to mentally visualise the concepts. Although VR was demonstrated to have improved motivation level; this does not automatically mean that enjoyment was included as shown in the interview where students pointed out that the effort spent to mine information from the VE was laborious. However, this result could also be attributed to Festinger's (1957) theory of dissonance (see section 7.8.2 for a more in-depth discussion of the theory).

Students in the interview sessions felt that the real-time interactive nature of the learning environment was one of the motivational factors. This was because it captured the attention of the students, the context was relevant and the system improved their confidence in the subject. Students also felt "safe" as they "do not need to be so careful" in their exploration of the environment.

7.6 Were students still able to collaborate while learning through a VR environment?

Students were able to collaborate by using the VE as a tool for discussion. They found that it could be used to demonstrate their ideas, enhancing flow of information and even to generate new ideas. This was shown in feedback in the interview as well as the questionnaire. This corroborates findings by Dalton (1990) who found that it is not merely the presence of collaboration that contributes to learning, but the quality of the interactions that is the determining factor. It would appear in this case that the use of VR stimulated meaningful and productive collaboration.

7.7 Did students prefer VR as a learning tool compared to traditional method?

It was found that although the user interface in the VE was a barrier initially, most Group I students were able to overcome this hurdle, as indicated by the high proportion of students who fed back that learning to use the interface was not an obstacle and that it was not difficult to use the VE to arrive at a solution. Students also reported that the VE made learning easier and that there was no discomfort or disorientation during the learning. The interview session also verified this.

However, the survey showed that there was no significant indication as to whether the tertiary level engineering students actually preferred VE to the traditional method of learning. Some reasons given were the initial difficulty of using the system, the effort required to mine information from the VE, and also that the method was not proven (compared to the traditional method). This was in direct contrast to findings in literature (Ainge 1996a, Osberg 1997), which seemed to suggest that students prefer to learn using VEs. However, these studies have children as subjects. The review in chapter 2 found that older students benefited less and were less motivated towards learning in a VE compared to younger children, because they were more able to internalise their mental models. Such a "maturation effect" may be one possible explanation for this finding. The other possibility could be because of their learning experiences in less flexible environments in later adolescence.

7.8 Other Observations

7.8.1 Problem Solving

Problem solving involves complex interactions between a multitude of cognitive, metacognitive and knowledge-based processes. Szetela and Nicol (1992) identify the following typical sequence of actions for successful problem solving:

- Obtain appropriate representation of the problem situation
- Consider potentially appropriate strategies
- Select and implement a promising solution strategy.
- Monitor the implementation with respect to problem conditions and goals.
- Obtain and communicate the desired goals.
- Evaluate the adequacy and reasonableness of the solution.
- If the solution is judged faulty or inadequate, refine the problem representation and proceed with a new strategy or search for procedural or conceptual errors.

When these steps are considered in terms of the characteristics of VR, a clear picture begins to emerge of how VR could aid student problem solving. Looking at how VR matches with each of the above steps, 1) VR may prove to be a powerful visualization tool for representing abstract problem situations. 2) Virtual worlds allow for a high degree of trial and error, which may encourage students to explore a greater range of possible solutions. 3) The student is free to interact directly with virtual objects, which allows for firsthand hypothesis testing. 4) The virtual world can be programmed to offer feedback that focuses the student's attention on specific mistakes, thereby enhancing students' ability to monitor their own progress. 5) The VR system can collect and display complex data in real time, which may help students obtain their desired goals. 6) The immersive nature of VR might enhance students' capability to retain and recall information, which could facilitate the evaluation of solutions. 7) The virtual world is a fluid environment well suited for the iterative process of refinement.

7.8.2 Theory of Cognitive Dissonance

Some of the results obtained in this research can be explained using Festinger's Theory of Cognitive Dissonance (Festinger, 1957). As presented by Festinger in 1957, when subjects encounter a new stimulus (information), their mind will organise it with other previously encountered stimuli. If the new stimulus does not fit the expected pattern or is inconsistent (dissonance), then the subjects will feel discomfort. The existence of dissonance, being psychologically uncomfortable, will motivate the subjects to reduce the dissonance and lead to avoidance of information likely to increase the dissonance. It follows that dissonance, resulting from a judgment made by a subject, can be reduced by removing negative aspects of the chosen alternative or positive aspects of the rejected alternative, and it can also be reduced by adding positive aspects to the chosen alternative or negative aspects to the rejected alternative. Altering the aspects of the decision alternatives to reduce dissonance would lead to viewing the chosen alternative as more desirable and the rejected alternative as less desirable. This effect has been termed spreading of alternatives, and the experimental paradigm has been termed the free-choice paradigm. This was demonstrated in various articles such as Brehm (1956), Festinger & Carlsmith (1959) and Shultz & Lepper (1996).

At the micro level, Festinger's theory could be related to findings in the survey questionnaire. For example, when asked how they preferred to get information, Group I students preferred interacting directly with the computer while Group II students preferred face-to-face contact, as predicted by the theory. Other instances seen in the experiment include cases where the t-test failed to detect a significant difference between the two groups, such as when both groups of students were asked if they learned better in a VR/VE environment, and when they were asked if they collaborated and whether they enjoyed their lessons more.

At the macro level, other issues such as the validity of the experiment could be called into question. For example, was the instructor biased? Were students in Group I and II affected by the theory when they took part in the exercise? Hence it was important that these issues be addressed in the design of the experiment. A test was conducted to ensure that feedback was not only based on the questionnaire and interview session, rather, these were used to delve deeper into the findings. The test was conducted blind to ensure equality in the marking. The two groups of students were drawn from the same pool and their examination results were compared to ensure that there was no significant difference, hence ensuring at least statistically, they had similar initial knowledge. In addition, both groups of students were those opting to take the CIM elective in the next semester, so they had the motivation to learn as they could pick up knowledge earlier than the rest of the students from the same pool. They were also randomly selected to go into the two groups. Care was also taken for the instructor to teach the subject to the two groups of students fairly. However, on hindsight, it would have been better if one additional step had been included in the experiment. That would be to conduct a satisfaction survey from both groups of students to indicate if lessons had been taught satisfactorily.

It was felt that the effect of Festinger's theory could not be avoided completely when collecting feedback from the survey as well as the interview sessions. Care could only be taken to minimise the effect while ensuring that the experiment was carried out in the proper context. This was demonstrated in the interview session when Group I students were able to relate the negative aspects of learning in the VR/VE (e.g. learning was unstructured, they had to mine out the information, there were too many options at the beginning, they had difficulty in using the interface) and Group II students were able to talk about the negative aspects of the traditional learning (e.g. learning was too stifling, learning was too boring, they felt that it slowed down their learning).

7.9 Opportunities for Future Research

One possible limitation of the study involves the test conducted with Group I students. The assessment was taken from the previous years' mid-semester test to ensure that the test used in the study was firstly, relevant to the domain area and secondly, applicable to both groups of students. However, it may not be have been the best assessment measure for learning in VE. Clues from the literature on constructivist learning indicate that teachers often judge students in terms of their test scores, but often fail to see people in terms of what they actually do (Strenio 1981, Reeves & Okey 1996). In order to develop VE as a learning tool, there is also a need to look into the appropriate design of assessments for it. Currently, this area is still lacking in research.

A major proposition of constructivist theory is that meaning is built socially (Vygotsky 1978). This requires students to interact with other students and teachers as they learn. With some exceptions, the study of learning in VEs has, for mainly technical reasons, been confined to the study of single students. Simply put, it is twice as expensive and complicated to put two students into a VE as it is to put one student there. In spite of the difficulties, technologies have developed to a stage where it is now possible to generate learning environments using massively multi-players online gaming (MMOG) techniques. The work then, is to develop tasks that require collaboration for success. Research on the collaborative nature of learning in VEs would provide clues as to how collaboration might help students construct knowledge together as they interact with metaphorical objects that represent abstractions. Although uncharted, it is one that is essential to explore.

Research has shown that contextual cueing is very important in guiding successful learning in VEs. What is an appropriate cueing mechanism in VEs? The method used in this study involves introduction of concepts before the treatment followed by simple cueing in the VE. This may not be the best method. What are the other alternatives and how did they help in student learning?

One of the potential problems identified in this research involves students having to overcome the barrier of learning to use the VE in order to begin learning. How did students overcome this barrier? Are there specific student characteristics or behaviour that helped these students to overcome this learning barrier? How much time is needed for students to effectively overcome this barrier?

In relation to implementing a curriculum augmented by the use of VR, what kind of teacher training is needed and what kind of subject is suitable for implementation? Taking into account the maturation effect, is there an optimum age for the introduction of the technology?

7.10 Conclusion

Through the experiment, considerable insight was gained into the complex relationship between VR's features and learning. An adaptation was made from Figure 7-1, Salzman et. al. (1999)'s hypothetical model (originally shown in fig. 2-1) to include findings from this study. Notice that each factor now has various sub-elements added. As in the original model, the links between VR's features, learner characteristics, the interaction and learning experiences, the concepts and finally the learning outcomes are shown. In conclusion, the study has found that:

- In conducting a study on using VE in student learning, pre-conditions such as justification of the need to use VE, ensuring relevant support, understanding the prior knowledge level of the students and ensuring a certain complexity level of the concept to be introduced have to be considered. This point is important because studies conducted without taking into account pre-conditions may lead to inaccurate conclusions as shown by various examples (Ainge 1996a, 1996b, Moore, Nawrocki & Simutis 1979, King 1975, Samuels 1970) in chapter 2.

- In using a VE, significant improvement has been made in the learning of problem-solving processes. Although there were no significant improvement in the learning of facts, application of formulae and differentiation processes, mean scores were noted to be higher. Hence learning using a VE is likely to be equally valuable, or more so, for some individuals compared to traditional learning, teacher-led lectures, notes, and face-to-face teaching.

- The VR features that students felt had great impact in their learning were found to be visualisation, trial & feedback, attention arousal, safety and cueing.

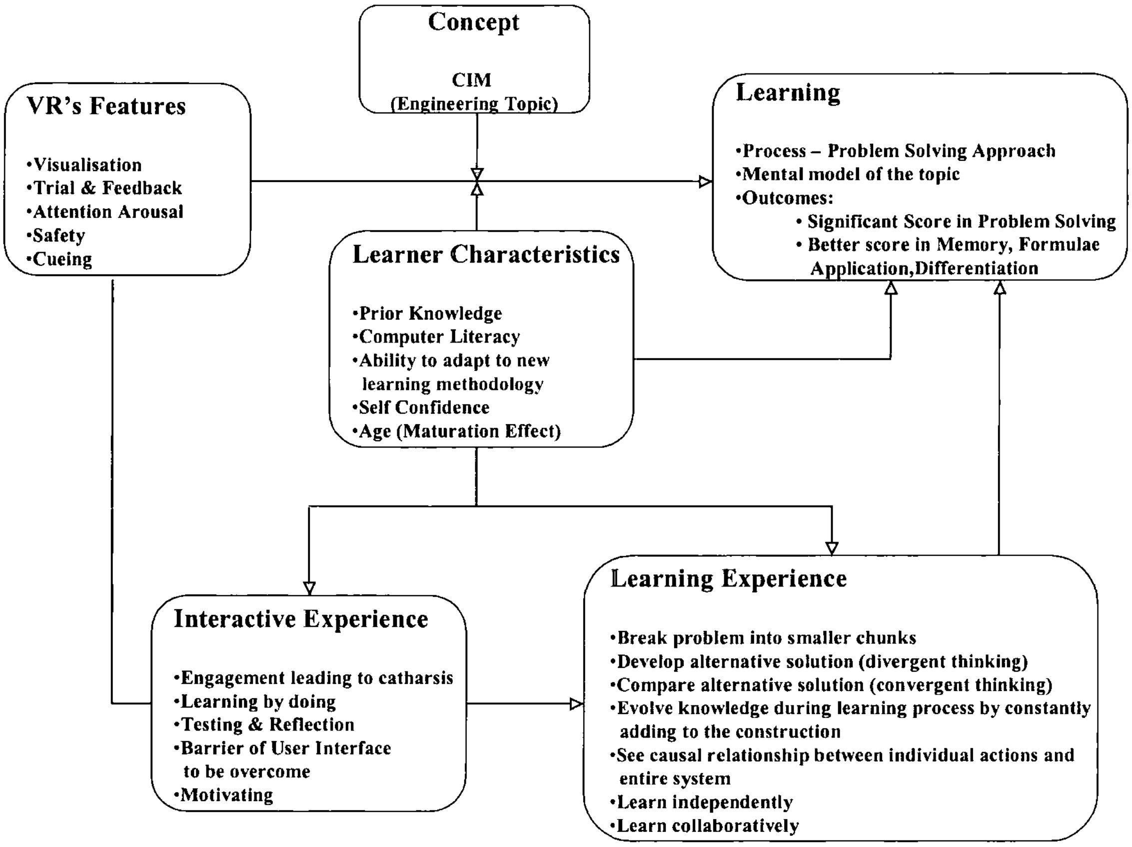


Figure 7- 1: Model of Learning in VR (adapted from Salzman et. al. 1999)

- The learner characteristics that affected the student learning were found to be prior knowledge, computer literacy, the ability to adapt to the new learning methodology, self- confidence and age.

- The interactive experiences in the VR that were felt to be most useful by the students were engagement leading to catharsis (an impulse generated within the learner to perform activities that lead to closure), learning by doing, testing and reflection, and the negative experience was that students had to overcome the barrier of learning via the new interface as well as the realisation from students that they had to work doubly hard to mine information from the tool.

- Learning experiences gained from the VE were the process of breaking problems into smaller chunks, developing alternatives, comparing alternatives, continuously evolving current knowledge based on new developments, seeing causal relationships between individual actions and the entire system and learning both independently and collaboratively. However, students appeared not to consider planning as important compared to other factors.

The findings from this research add to the pool of knowledge regarding the design and use of VR and VEs in education by enhancing the model proposed by Salzman et. al. in 1999. Other pertinent points gained during the research were equally important. One should not advocate one single learning theory, even in VR. The approach used has to take into account the prior knowledge of the learners. For example, a behavioural approach can effectively facilitate mastery of the content, while cognitive strategies are useful in teaching problem solving tactics where defined facts and rules are applied to unfamiliar situations. Constructivist strategies are suited to dealing with ill-defined problems through reflection-in-action (Schwier 1995). Hence, an approach requiring an understanding of the prior knowledge of the learners and also a combined learning strategy is seen as more advantageous. For example, research shows that novices are often unable to allocate attentional resources effectively, nor are they able to organise materials properly in order to construct meaning (see sections 2.2.3 and 3.4). This is especially true for visual knowledge (Chanlin 1999).

The current focus of learning is on the parts and not the whole system. Students learn to solve discipline specific problems rather than complex multidisciplinary problems. This becomes problematic when students make the transition from academy to industry as this requires decision making that is not strictly discipline based; rather it is a complex multidisciplinary team approach to problem solving. Having the ability to understand abstract and complex information and to make connections across domain areas and disciplines will help bridge this gap.

Attention should be drawn to the fact that VR is often "over-hyped" in the popular press and the popular imagination. Those who study the way in which youngsters act in and learn from VEs are easily impressed by the enthusiasm with which students take to VR and by their adeptness with the technology; it is very easy to conclude that VR is all it takes to help less able and less motivated students to become actively and enthusiastically engaged in learning complex material. For scientists, there is a need to guard against such advocacy. There is a need to gather evidence regarding the relative effectiveness of VEs, and to present this to the community of practitioners objectively.

The lessons shared in this research should be useful for updating the design, use and evaluation of VR learning environments. However, it should be recognised that the lessons learned to date provide only initial insights into a very complex web of relationships. Substantial additional research is necessary to elaborate and expand the current body of knowledge.

BIBLIOGRAPHY

Ainge D. (1996a). Upper primary students constructing and exploring three-dimensional shapes: A comparison of virtual reality with card nets. *Journal of Educational Computing Research,* Vol. 14, No. 4, pp. 345-369.

Ainge D. (1996b). Grade 6 children's recall of detail: VR compared with photographs. *VR in the Schools,* Vol. 1, No. 4, pp. 1-4.

Anderson J.R. (1980). *Cognitive psychology and its implications.* CA: W.H. Freeman.

Anderson R. & Biddle W. (1975). On asking people questions about what they are reading. In Bower G. (Ed.), *Psychology of learning and motivation* (Vol. 9) (pp. 89-132). NY: Academic Press.

Andre T. (1986). Problem solving and education. In Phye G.D. & Andre T.(Eds.), *Cognitive classroom learning: Understanding, thinking and problem solving* (pp. 169-204). CA: Academic Press Inc.

Antonietti A., Imperio E., Rasi C. & Sacco M. (2001). Virtual reality and hypermedia in learning to use a turning lathe. *Journal of Computer Assisted learning,* Vol. 17, pp. 142-155.

Arthur E., Hancock P. & Telke S. (1996). Navigation in virtual environments. *Proceedings of the SPIE – International Society of Optical Engineering,* 2704, pp. 77-85.

Ausubel D. (1978). *Educational psychology: A cognitive view.* NY: Holt, Rinehart & Winston.

Avgerinou M. & Ericson J. (1997). A review of the concept o visual literacy. *British Journal of Educational Technology,* Vol. 28, No. 4, pp. 280-291.

Bandura A. & Walters R. H. (1963). *Social learning and personality development.* NY: Holt, Rinehart and Winston.

Bandura A. (1977). Self efficacy: Toward a unifying theory of behavioral change. *Psychological Review,* Vol. 84. Pp. 191-215.

Bandura A. (1978). The self system in reciprocal determinism. *American Psychologist,* Vol. 33, pp. 344-358.

Bandura A. (1982). Self-efficacy mechanism in human agency. *American Psychologist,* Vol. 37, pp. 122-147.

Barrows H.S. (1986). A taxonomy of problem-based learning methods. *Medical Education,* Vol. 20, No. 6, pp. 481-486.

Bartlett F.C. (1932). *Remembering: A study in experimental and social psychology.* Cambridge, England: Cambridge University Press.

Bates J.A. (1979). Extrinsic reward and intrinsic motivation: A review with implications for the classroom. *Review of Educational Research,* Vol. 49, No. 4, pp. 557-579.

Beck R.N. (1979). *Handbook in social philosophy.* NY: Macmillan.

Bereiter C. (1991). Implications of connectionism for thinking about rules. *Educational Researcher,* Vol. 20, April, pp. 10-16.

Berlyne D.E. (1965a). Motivational problems raised by exploratory and epistemic behaviour. In Koch S. (Ed.), *Psychology: A study of a science (Vol. 5).* NY: McGraw-Hill.

Berlyne D.E. (1965b). *Structure and direction in thinking.* NY: Wiley.

Betz J.A. (1995). Computer games: Increases learning in an interactive multidisciplinary environment. *Journal of Educational Technology Systems*, Vol. 24, pp. 195-205.

Bonwell C.C. & Eison J.A. (1991). *Active learning: Creating excitement in the classroom.* Washington: George Washington University, School of Education and Human Development.

Bouchlaghem N., Wilson A., Beacham N. & Sher W. (2002). Computer imagery and visualization in built environment education: The CAL-visual approach. *Innovations in Education and Teaching International*, Vol. 39, No. 3, pp. 225-236.

Braden R. A., & Hortin J. A. (1982). Identifying the theoretical foundations of visual literacy. *Journal of Visual Verbal Languaging*, Vol. 2, No.2, pp. 37-42.

Braun C. (1969). Interest-loading and modality effects on textual response acquisition. *Reading Research Quarterly*, Vol. 4, pp. 428-444.

Brehm J. W. (1956). Postdecision changes in the desirability of alternatives. *Journal of Abnormal and Social Psychology*, 52, pp. 384-389.

Bricken, M. & Byrne, C. (1992). Summer Students in Virtual Reality: A Pilot Study on Educational Applications of VR Technology. *HIT Lab Technical Report R-92-1.* Seattle: University of Washington, Human Interface Technology Laboratory. Ref: http://www.hitl.washington.edu/publications/r-92-1/

Bricken, M., & Byrne, C.M. (1993). Summer students in virtual reality: A pilot study on educational applications of virtual reality technology. In Wexelblat A. (Ed.), *Virtual reality applications and explorations.* Cambridge, MA: Academic Press Professional.

Broadbent D.E. (1971). *Decision and stress.* NY: Academic Press.

Brown A.L. (1980). Metacognitive development and reading. In Spiro R.J., Bruce B.C. & Brewer W.F. (Eds.), *Theoretical issues in reading comprehension.* Hillsdale, NJ: Erlbaum.

Brown D.J. & Cunningham S. (1990). Visualisation in higher education. *Academic Computing*, Vol. 4, No. 6, pp. 24-25, 41-45.

Brown D.J., Cobb S.V. & Eastgate R.M. (1995). Learning in virtual environments (LIVE). In Earnshaw R.A., Vince J.A. & Jones H. (Eds.), *Virtual reality applications* (pp. 245-252). London: Academic Press.

Brown D.J., Kerr S.J. & Wilson J.R. (1997). VE and special needs education: The LIVE program at the University of Nottingham. *Communications of the ACM*, Vol. 40, No. 8, pp. 72-75.

Brown D.J., Mikropoulos T.A. & Kerr S.J. (1996). *A virtual laser physics laboratory. VR in the schools*, Vol. 2, No. 3.Ref: http://www.soe.ecu.edu/vr/vrits/2-3brown.htm

Brown J. (1983). Learning-by-doing revisited for electronic learning environments. In White M.A. (Ed.), *The future of electronic learning* (pp. 13-32). Hillsdale, NJ: Lawrence Erlbaum Associates.

Brown J.S. (1989). Toward a new epistemology for learning. *People and Computers*, February 19, pp. 266-282.

Brown J.S., Collins A. & Duguid P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, Vol. 18, Jan/Feb, pp. 32-42.

Bruner J. (1990). *Acts of Meaning.* Cambridge: MA: Harvard University Press.

Bruner J.S. (1964). The course of cognitive growth. *American Psychologist*, Vol. 19, pp. 1-15.

Bruner J.S. (1973). *Beyond the information given: Studies in the psychology of knowing.* NY: Norton.

Burns R.B. (2000). *Introduction to Research Methods* (4th ed.). London: Sage Publications Ltd.

Butterfield E.C., Albertson L.R. & Johnston J.C. (1993). On making cognitive theory more general and developmentally pertinent. *Research on Memory Development: State-Of-The-Art and FutureDirections: Conference proceedings 1993*, Castle Ringberg, Germany, June 1993.

Byrne C.M. (1993). Virtual reality and education. *Proceedings of IFIP WG3.5 International Workshop Conference*, pp. 181-189.

Byrne C.M. (1996). *Water on tap: The use of virtual reality as an educational tool.* Ph.D. Dissertation, College of Engineering, University of Washington, Seattle, WA.

Calder B.J. & Staw B.M. (1975). Self-perception of intrinsic and extrinsic motivation. *Journal of Personality and Social Psychology*, Vol. 31, pp. 599-605.

Caraballo A. (1985). *An experimental study to investigate the effects of computer animation on the understanding and retention of selected levels of learning outcomes.* Doctoral dissertation. The Pennsylvania State University.

Case R. & Bereiter C. (1984). From behaviourism to cognitive behaviourism to cognitive development: Steps in the evolution of instructional design. *Instructional Science*, Vol. 13, pp. 141-158.

Chanlin L.J. (1999). Visual treatment for different prior knowledge. *International Journal of Instructional Media*, Vol. 26, No. 2, pp. 213-210.

Clancey W.J. (1993). Situated action: A neuropsychological interpretation: Response to Vera and Simon. *Cognitive Science*, Vol. 17, pp. 137-148.

Clark R. & Sugrue B. (1988). Research on instructional media, 1978-1988 In Ely D., Broadbent B. & Wood R. (Eds.), *Educational media and technology yearbook: 1988* (Vol. 14). Englewood: Libraries Unlimited.

Clark R.E. (1983). Reconsidering research on learning with media. *Review of Educational Research*, Vol. 53, No. 4., pp. 445-459.

Cognitive & Technology Group at Vanderbilt (1991). Technology and the design of generative learning environments. *Educational Technology*, Vol. 31, May, pp. 16-19.

Cognition & Technology Group at Vanderbilt. (1992a). Technology and the design of generative learning environments. In Duffy T.M. & Jonassen D.H. (Eds.) *Constructivism and the technology of instruction: A conversation* (pp. 77-89). Hillsdale, NJ: Lawrence Erlbaum.

Cognition & Technology Group at Vanderbilt. (1992b). The Jasper experiment: An exploration of issues in learning and instructional design. *Educational Technology Research and Development*, Vol. 40, No. 1, pp. 65-80.

Cohen J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Cohen J. (1992). A power primer. *Psychological Bulletin*, 112, pp. 155-159.
Cohen L., Manion L. & Morrison K. (2000). *Research methods in education* (5th ed.). London: RoutledgeFalmer.

Collins A., Brown J.S. & Newman S. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. In Resnick L.B. (Ed.) *Knowing, Learning and Instruction: Essays in honour of Robert Glaser.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Craik F. & Lockhart R. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behaviour*, Vol. 11, pp. 761-784.

Cromby J.J., Standen P.J. and Brown D.J. (1995). Using Virtual Environments in Special Education. *VR in the Schools.* Vol. 1, No. 3, pp. 1-4.

Cromby J.J., Standen P.J. and Brown D.J. (1996) The potentials of virtual environments in the education and training of people with learning disabilities" *Journal of Intellectual Disability Research*, Vol. 40, No. 6, pp. 489-501.

Csikszentmihalyi M. (1990). *Flow: The psychology of optimum experience.* NY: Harper & Row.

Cuban L. (1986). *Teachers and machines: The classroom use of technology since 1920.* NY: Teachers College Press.

Culler J. (1990). Fostering post-structuralist thinking. Paper presented at the Annual Meeting of the American Educational Research Association, Boston.

Cunningham D.J. (1992a). Beyond educational psychology: Steps towards an educational semiotic. *Educational Psychology Review*, Vol. 4, pp. 411-421.

Cunningham D.J. (1992b). Assessing constructions and constructing assessments: A dialogue. In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 35-44). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Czikzentmihalyi M. & Czikzentmihalyi I.S. (1988). *Optimal experience: Psychological studies of flow in consciousness.* NY: Cambridge University Press.

Dalton D. (1990). The effects of cooperative learning strategies on achievement and attitudes during interactive video. *Journal of Computer-Based Instruction*, Vol. 17 No. 1, pp. 8-16.

Deci E.L. (1985). Intrinsic motivation and self-determination in human behaviour. NY: Plenum Press.

Dede C. (1992). The future of multimedia: Bridging to virtual worlds. *Educational Technology*, May pp. 54-60.

Dede C. (2000). Emerging influences of information technology on school curriculum. *Journal of Curriculum Studies*, Vol. 32, No. 2, pp. 281-303.

Dembo M.H. (1994). *Applying educational psychology* (5th Ed.). NY: Longman Publishing Group.

Denzin N.K. (1970). *The research act in sociology: a theoretical introduction methods.* London: Butterworth.

Dertouzos M. & Gates B. (1998). *What will be: How the new world of information will change our lives.* NY: Harper.

Dewey J. (1916). *Democracy and education: An introduction to the philosophy of education.* NY: Macmillan.

Di Vesta F. (1987). The cognitive movement and education. In Glover J. & Royce R. (Eds.), *Historical foundations of education psychology* (pp. 203-233). NY: Plenum Press.

Dick W. (1992). An instructional designer's view of constructivism. In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 91-98). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Discoll M.P. (1994). *Psychology of learning for instruction.* MA: Allyn & Bacon.

Dodd D.H. & White R.M. (1980). *Cognition, mental structures and processes.* Boston: Allyn and Bacon.

Donald M. (1991). *Origins of the modern mind.* Cambridge: Harvard University Press.

Draper S.W. & Norman D. (1986). Introduction. In Norman D.A. & Draper S.W. (Eds.), *User-centred system design.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Duell O.K. (1986). Metacognitive skills. In Phye G.D. & Andre T. (Eds.), *Cognitive classroom learning* (pp. 205-242). Orlando: Academic Press.

Duffy T.M. & Jonassen D.H. (1992). Constructivism: New implications for instructional technology. In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 1-16). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Dweck C. (1986). Motivational processes affecting learning. *American Psychologist*, Vol. 41, pp. 1040-1048.

Dweck C. (1991). Self-theories and goals: their role in motivation, personality and development. *Nebraska Symposium on Motivation*, Vol. 38. University of Nebraska Press.

Dweck C. S. & Leggett E.L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review*, Vol. 95, pp. 256-273.

Dweck C.S. & Elliot E.S. (1983). Achievement motivation. In Mussen P.H. (Gen. Ed.) & Hetherington E.H. (Vol. Ed.). *Handbook of child psychology: Vol. IV. Social and personality development* (pp. 643-691). NY: Wiley.

Dwyer F.M. (1972). *A guide for improving visualized instruction.* State College, PA: Learning Services.

Dwyer F.M. (1978). *Strategies for improving visual learning.* State College, PA: Learning Services.

Dwyer F.M. (1987). *Enhancing visualized instructions: Recommendations for practitioners.* State College, PA: Learning Services.

Elliot E.S. & Dweck C.S. (1988). Goals: An approach to motivation and achievement. *Journal of Personality and Social Psychology*, Vol. 54, pp. 5-12.

Erickson T. (1993). Artificial realities as data visualisation environments. In Wexelblat A. (Ed.), *Virtual reality: Applications and explorations* (pp. 1-22). NY: Academic Press Professional.

Ertmer P.A.& Newby T.J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, Vol. 6, No. 4, pp. 50-70

Feaver W. (1977). *When we were young: Two centuries of children's book illustration.* London: Thames & Hudson.

Ferrington G and Loge K. (1992). Virtual reality: A new learning environment". *Computing Teacher*, Vol. 19, No. 7, pp. 16-19.
Festinger L. (1957). *A Theory of Cognitive Dissonance.* Evanston, Illinois: Row Peterson & Co.

Festinger L., & Carlsmith J. M. (1959). Cognitive consequences of forced compliance. *Journal of Abnormal and Social Psychology*, 58, pp. 203-210.

Fitz-Gibon C.T. (1997). *The value added national project. Final report.* London: School Curriculum and Assessment Authority.

Fitz-Gibbon C.T. & Morris L.L. (1987). *How to analyze data.* Sage Publications Inc., CA.

Flavell J.H. (1979). Metacognition and cognitive monitoring: A new area of cognitive developmental inquiry. *American Psychologist*, Vol. 34, pp. 906-911.

Forman G. & Pufall P. (1988). Constructivism in the computer age: A reconstructive epilogue. In Forman G. & Pufall P. (Eds.), *Constructivism in the computer age* (pp. 235-250). Hillsdale, NJ: Lawrence Erlbaum Associates.

Foster J.F. (1988). *Data analysis using SPSS for Windows: A beginner's guide.* London: Sage Publications Ltd.

Francis G.A. & Tan H.S. (1999). Virtual Reality as a Training Instrument, *The Temasek Journal*, Vol. 7, pp. 4 –15.

Fry J.P. (1972). Interactive relationship between inquisitiveness and student control of instruction. *Journal of Educational Psychology*, Vol. 3, pp. 459-465.

Furness, T. (1986). Configuring Virtual Space for the Super Cockpit. In M. Ung (Ed.) *Proceedings of Aerospace Simulation II*, pp. 103-110.

Gagné E. (1985). *The cognitive psychology of school learning.* Boston: Little, Brown and Company.

Gagné R.M. & Driscoll M.P. (1988). *Essentials of learning for instruction* (2nd Ed.). Englewood Cliffs, NJ: Prentice-Hall.

Gagné R.M. & Glaser R. (1987). Foundations in learning research. In Gagné R.M. (Ed.), *Instructional Technology: Foundations* (pp. 49-83). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gagné R.M. (1985). *The conditions of learning* (4th ed.). NY: Holt, Reinhart & Winston.

Gagné R.M., Briggs L. & Wager W. (1992). *Principles of instructional design* (4th Ed.). NY: Holt, Rinehart & Winston.

Gardiner L.F. (1994). *Redesigning higher education: Producing dramatic gains in student learning.* Washington DC: Associate for the Study of Higher Education, ERIC Clearinghouse on Higher Education.

Gardner H. (1983). *Frames of mind: The theory of multiple intelligences.* NY: Basic Books.

Gibson J.J. (1977). The theory of affordance. In Shaw R. & Bransord J. (Eds.), *Perceiving, acting, and knowing.* Hillsdale, NJ: Erlbaum.

Glaserfield E. v. (1995). *Radical constructivism: A way of knowing and learning.* London: Falmer Press.

Goodman N. (1984). *Of mind and other matters.* Cambridge, MA: Harvard University Press.

Goodnow J. (1977). *Children's drawing.* London: Open Books.

Graham S. & Barker G.P. (1990). The down side of help: An attributional-developmental analysis of helping behaviour as a low-ability cue. *Journal of Educational Psychology*, Vol. 82, No. 1, pp. 7-14.

Green S.B., Salkind N.J. & Akey T.M. (2000). *Using SPSS for windows: Analysing & understanding data*, (2nd Ed.). NJ:Prentice-Hall Inc.

Grigson A. (1995). Worlds of Virture, *Manufacturing Engineer*, Vol. 74, No. 5, pp. 222-224.

Guthrie E.R. (1933). Association as a function of the time interval. *Psychological Review*, Vol. 37, pp. 412-428.

Guttman J., Levin J. & Pressley, M. (1977). Pictures, partial pictures and young children's oral prose learning. *Journal of Educational Psychology*, Vol. 69, pp. 473-480.

Halpern D. (1992). *Sex differences in cognitive abilities*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hamaker C. (1986). The effects of adjunct questions on prose learning. *Review of Educational Research*, Vol. 56, pp. 212-242.

Hammersley M. (1993). Educational Research: Current Issues. Open University/Paul Chapman Publishing Ltd.

Hanna D.E. (2000). Emerging approaches to learning in collegiate classrooms. In Hanna D.E. & Associates (Eds.), *Higher Education in an Era of Digital Competition: Choices and Challenges* (pp.45-69). Madison: Artwood Publishing.

Hanna J. (1986). Learning environment criteria. In Ennals R., Gwyn R & Zdravchev L. (Eds.), *Information technology and education: The changing school*. Chichester, UK: Ellis Horwood.

Hannafin M. & Rieber L.P. (1989). Psychological foundations of instructional design for emerging computer-based instructional technologies: Part I. *Educational Technology Research and Development*, Vol. 37, No. 2, pp. 91-101.

Harding M. (1998). Virtual reality the art of engineering. *Design Engineering*, April, pp. 19-21.

Harré R. & Secord P. (1972). *The explanation of social behaviour*. Oxford: Basil Blackwell.

Harste J.C. (1989). *New policy guidelines for reading: Connecting research and practice*. Urbana, IL: National Council of Teachers of English.

Hays R.T. & Vincenzi D.A. (2000). Fleet assessment of a virtual reality training system. *Military Psychology*, Vol. 12, No. 3, pp. 161-186.

Heath S.B. (2000). Seeing our way into learning. *Cambridge Journal of Education*, Vol. 30, No. 1, pp. 121-132.

Heeter C. (1992). Being there: The subjective experience of presence. *Presence: Teleoperators and Virtual Environments*, Vol. 1, No. 1, pp. 262-271.

Hegarty M. & Sims V.K. (1994). Individual differences in mental animation during mechanical reasoning. *Memory and Cognition*, Vol. 22, No. 4, pp. 411-430.

Hitchcock G. & Huges D. (1995). *Research and the teacher* (2nd ed.). London: Routledge.

Huck S.W., Cormier W.H. & Bounds, W.G. (1974). *Reading statistics and research*. NY: Harper Collins Publishers Inc.

Huntington F. (1984). Thinking is an adventure. *InCider*. October. Pp. 33-36.

Hutchins E.L., Hollan J.D. & Norman D.A. (1986). Direct manipulation interfaces. In Draper S.W. & Norman D.A. (Eds.), *User centered system design: New Perspectives on human-computer interaction*.

Hillsdale NJ: Lawrence Erlbaum Associates.

Johnson-Laird P.N. (1988). *The computer and the mind.* Cambridge: Harvard University Press.

Jonassen D.H. (1988). *Instructional design for microcomputer courseware.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Jonassen D.H. (1992). Evaluating constructivist learning. In Duffy T.M. & Jonassen D.H. (Eds.) *Constructivism and the technology of instruction: A conversation* (pp. 137-148). Hillsdale, NJ: Lawrence Erlbaum.

Jonassen D.H. (1994). Thinking technology: Toward a constructivist design model. *Educational Technology*, Vol. 34, No. 4, pp. 34-7.

Jonassen D.H. & Reeves T.C. (1996). Learning with technology: Using computers as cognitive tools. In Jonassen D.H. (Ed.), *Handbook of Research for Educational Communications and Technology* (pp. 693-719). NY: Macmillan.

Jones B., Valdez G., Nowakowski J., & Rasmussen C. (1994). *Designing Learning and Technology for Educational Reform.* Washington: North Central Regional Educational Laboratory: US Department of Education Office of Educational Research and Improvement, Educational Resources Information Center.
Ref:
http://www.ncrel.org/sdrs/engaged.htm

Kearsley G. & Shneiderman B. (1999). Engagement theory. Ref: http://home.sprynet.com/~gkearsley/engage.htm

Keller J.M. (1983). Motivational design of instruction. In Reiguluth C.M. (Ed.), *Instructional design theories and models: An Overview of their current status* (pp. 386 -- 343). Hillsdale, NJ: Lawrence Erlbaum Associates.

Keller J. M. (1987). Strategies for Stimulating the Motivation to Learn. *Performance & Instruction*, Vol. 26, No.8, pp. 1-7.

Keller J. M. & Suzuki, K. (1988). Use of the ARCS motivation model in courseware design. In Jonassen D. (Ed.), Instructional designs for microcomputer courseware (pp. 401-434). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kellog R. (1969). *Analysing children's art.* Palo Alto, CA: National Press.

Kelly R.V. (1996). The end of cognitive bulimia. *Virtual Reality Special Report*, Vol. 3, No. 1, pp. 38-50.

Kerlinger F.N. (1970). *Foundations of behavioural research.* NY: Holt, Rinehart & Winston.

King W. (1975). *A comparison of three combinations of text and graphics for concept learning.* (Report No. NPRDC-TR-76-16). San Diego, CA: Navy Personnel Research and Development Center. (ERIC Document Reporduction Service No. ED 112 936).

Kintsch W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*, Vol.95, pp. 163-182.

Kobayashi S. (1986). Theoretical issues concerning superiority of pictures over words and sentences in memory. *Perceptual and Motor Skills*, Vol. 63, pp. 783-792.

Koffka K. (1922) Perception: An introduction to the Gestalt-theorie. *Psychological Bulletin*, Vol. 19, pp. 531-585.

Köhler W. (1925). *The mentality of apes.* London: Routledge & Kegan Paul.

Kozma R.B. (1994). Will media influence learning? Reframing the debate. *Educational Technology Research and Development*, Vol. 42, No. 2, pp. 7-19.

Kraft R. & Sakofs M. (1989). *The theory of experiential education.* Boulder, CO: Association for Experiential Education.

Kress G. & van Leeuwen T. (1996). *Reading images: The grammar of visual design.* London: Routledge.

Kulhavy R. (1977). Feedback in written instruction. *Review of Educational Research*, Vol. 47, pp. 211-232.

Laurel B. (1991). *Computers as theatre.* Reading, MA: Addison-Wesley.

Laurillard D. (1993). *Rethinking university teaching: A framework for effective use of educational technology.* London: Routledge.

Laurillard D. (1995). Multimedia and the changing experience of the learner. *British Journal of Educational Technology*, vol. 26, no. 3, pp. 179-189.

Lawrence A. & Pantelidis V. (1999). Virtual reality: The virtual reality and education laboratory at East Carolina University. *T H E Journal*, Nov. 99, Vol. 27, Issue 4, pp. 48-53.

Leahey T.H. & Harris R.J. (1989). *Human learning* (2nd Ed.). Englewood Cliffs, NJ: Prentice-Hall.

LeCompte M. & Preissle J. (1993). *Ethnography and qualitative design in educational research* (2nd Ed.). London: Academic Press Ltd.

Lesgold A., Levin J., Shimron J. & Guttman J. (1975). Pictures and young children's learning form oral prose. *Journal of Educational Psychology*, Vol. 67, pp. 636-642.

Lesgold A., McCormick C. & Golinkoff R. (1975). Imagery training and children's prose learning. *Journal of Educational Psychology*, Vol. 67, p. 663-667.

Levie W. (1987). Research on pictures: A guide to the literature. In Willows D. & Houghton H. (Eds.), *The psychology of illustration, volume 1: Instructional issues* (pp. 1-50). NY: Springer-Verlag.

Levin J. & Divine-Hawkins P. (1974). Visual imagery as a prose-learning process. *Journal of Reading Behaviour*, Vol. 6, pp. 233-243.

Levin J. & Kaplan S.A. (1972). Imaginal facilitation of paired-associate learning: A limited generalisation? *Journal of Educational Psychology*, Vol. 63, pp. 429-432.

Levin J. & Lesgold A. (1978). On pictures in prose. *Educational Communications and Technology Journal*, Vol. 26, No. 3, pp. 233-243.

Levin J., Anglin G. & Carney R. (1987). On empirically validating functions of pictures in prose. In Willows D. & Houghton H. (Eds.), *The psychology of illustration, volume I: Instructional issues* (pp. 51-85). NY: Springer-Verlag.

Lewis A.C. (1993). *Changing the odds: Middle school reform in progress 1991-1993.* NY: The Edna McConnell Clark Foundation.

Lewis J.E. (1994). Virtual reality: Ready or not. *Technos*, Vol. 3, No. 1, pp. 10-15.

Lin G.C. (1997). The latest research trends in CIM. *Proceedings of the 4th International Conference on Computer Integrated Manufacturing (ICCIM' 97)*, Vol. 1, pp. 26-33.

Locke E.A., Shaw K.N., Saari L.M. & Latham G.P. (1981). Goal setting and task performance: 1969-1980. *Psychological Bulletin*, Vol. 90, pp. 125-152.

Loftin R.B. & Kennedy P.J. (1995). Training the hubble space telescope flight team. *IEEE Computer Graphics and Applications*, Vol. 15, No. 5, pp. 31-37.

Luetner D. (1993). Guided discovery learning with computer-based simulation games: Effect of adaptive and non-adaptive instructional support. *Learning and Instruction*, Vol. 3, pp. 113-132.

Lunzar E. (1986). Cognitive development: Learning and the mechanisms of change. In Phye G.D. & Andre T.(Eds.), *Cognitive classroom learning: Understanding, thinking and problem solving* (pp. 227-316). CA: Academic Press Inc.

Malone T.W. (1981). Towards a theory of intrinsically motivating instruction. *Cognitive Science*, Vol. 5, pp. 333-370.

Mandl H. & Levin J.R. (1989). *Knowledge acquisition from text and pictures.* North Holland: Elsevier.

Martin B.L. (1987). Aesthetics and media: Implications for the design of instruction. Educational Technology, Vol. 26 (June), pp. 15-21.

Maslow A. (1968). *Toward a psychology of being.* NY: Van Nostrand.

Mayer R. (1979). Can advance organisers influence meaningful learning? *Review of Educational Research*, Vol. 49, No. 2, pp. 371-383.

Mayer R. (1983). *Thinking, problem solving, cognition.* NY: W.H. Freeman & Company.
McClelland D., Atkinson J.W., Clark R.W. & Lowell E.L. (1953). *The achievement motive.* NY: Appleton-Century-Crofts.

McLellan H. (1994). Virtual reality and multiple intelligences: Potentials for higher education. *Journal of computing in higher education*, Vol. 5, No. 2, pp. 33-66.

McLellan H. (1996). Virtual realities. In Jonassen D. (Ed.), *Handbook of research for educational communications and technology* (pp. 457-487). NY: Simon & Schuster.

McQuade D. & McQuade C. (2000). *Seeing Writing.* NY: Bedford.

Mecklenburger J. (1993). To start a dialogue: The next generation of America's schools. *Phi Kappa Phi Journal.* LXXIII (4), pp. 40-43.

Merrill M.D. (1992). Constructivism and instructional design. In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 99-114). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Moore M., Nawrocki L. & Simitus Z. (1979). *The instructional effectiveness of three levels of graphics displays for computer-assisted instruction.* (Report No. ARI-TP-359). Arlington, VA: Army Research Institute for the Behavioral and Social Sciences. (ERIC Document Service No. ED 178 057).

Moshell J.M., Blau B.S., Knerr B., Lampton B. and Bliss J.P. (1993). A research testbed for virtual environment training applications. *VRAIS'93 Proceedings of the IEEE Virtual Reality Annual International Symposium*, pp. 83-89.

Neal L. (1990). Implications of computer games for system design. In Diaper D., Gilmore D., Cockton G. and Shackel B. (Eds.). *Human-Computer Interaction – Proceedings of INTERACT'90* (pp. 45-57). Elsevier, North Holland.

Nelson T.O. (1977). Repetition and depth of processing. *Journal of Verbal Learning and Verbal Behaviour*, Vol. 16, pp. 151-171.
Newby G. (1993). Virtual reality. In Williams M.E. (Ed.), *Annual Review of Information Science and Technology* (pp. 187-229). USA: Information Today Inc.

Newell A. (1990). *Unified theories of cognition.* Cambridge: Harvard University Press.

Norman D. (1982). *Learning and memory.* SF: W.H. Freeman & Company.

Norman D.A. & Bobrow D.G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, Vol. 7, pp. 44-64.

Oppenheimer T. (1997). The computer delusion. *The Atlantic Monthly*, July, pp. 45-62.

Osberg K.M. (1993). Virtual reality & education: A look at both sides of the sword. (Technical Report R-93-7). Seattle: University of Washington, Human Interface Technology Laboratory. Ref: http://www.hitl.washington.edu/publications/r-93-7/

Osberg K.M. (1995). Virtual reality and education: Where imagination and experiences meet. *VR in the Schools*, Vol. 1, No. 2, pp. 1-3.

Osberg K.M. (1997). *Constructivism in Practice: The Case for Meaning-Making in the Virtual World.* Doctoral Dissertation, University of Washington.

Osberg K.M., Winn W., Rose H., Hollander A., Hoffman H., Char, P. (1997). The effect of having grade seven students construct virtual environments on their comprehension of science. *Proceedings of Annual Meeting of the American Educational Research Association.* Ref: http://www.hitl.washington.edu/publications/r-97-19/

Paivio A. (1990). *Mental representations: A dual coding approach* (2nd Ed.). NY: Oxford University Press.

Paivio A. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology*, Vol. 45, pp. 255-287.

Papert S. (1980). *Mindstorms: Children, computers and powerful ideas.* NY: Basic Books.

Parlett M. & Hamilton D. (1976). Evaluation as illumination. In Tawney D. (Ed.) *Curriculum evaluation today: trends and implications.* London: Macmillian, pp. 84-101.

Pentelidis V.S. (1993). Virtual reality in the classroom, *Educational Technology*, Vol. 33, No. 4, pp. 23-27.

Pentelidis V.S. (1995). Using virtual reality to teach local history. *VR in the Schools*, Vol. 1, No. 3, pp. 15.

Perkins D.N. (1992a). Technology meets constructivism: Do they make a marriage? In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 45-55). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Perkins D.N. (1992b). What constructivism demands of the learner. In Duffy T.M. & Jonassen D.H. (Eds.), *Constructivism and the technology of instruction: A conversation* (pp. 161-165). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Perret-Clermont A., Perret J. & Bell N. (1991). The social construction of meaning and cognitive activity in elementary school children. In Resnick L.B., Levine J.M. & Teasley (Eds.), *Socially Shared Cognition* (pp.

41-62). Washington: American Psychological Association.

Piaget J. (1952). *The origins of intelligence in children.* NY: International University Press.

Piaget J. (1970). *Genetic epistemology.* NY: Columbia University Press.

Poggenpohl S.H. & Winkler D.M. (1992). Diagrams as tools for worldmaking. *Visible Language*, vol. 26, no. 3-4, pp. 252-69 Sum – Fall.

Prensky M. (2001). *Digital game-based learning.* NY: McGraw-Hill.

Pressley M. (1976). Mental imagery helps eight-year-olds remember what they read. *Journal of Educational Psychology*, Vol. 68, pp. 355-359.

Pressley M. (1977). Imagery and children's learning: Putting the picture in developmental perspective. *Review of Educational Research*, Vol. 47, No. 4, pp. 585-622.

Punch K.F. (1998). *Introduction to social research: Quantitative & qualitative approaches.* London: Sage Publications Ltd.

Quinn C.N. (1997). Engaging learning. *Instructional Technology Forum.* Ref: http://itech1.coe.uga.edu/itforum/paper18/paper18.html.

Reed S. (1985). Effect of computer graphics on improving estimates to algebra word problems. *Journal of Educational Psychology*, Vol. 77, No. 3, pp. 285-298.

Reeves T.C. & Okey J.R. (1996). Alternative assessment for constructivist learning environments. In Wilson B.G. (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 191-200), NJ: Educational Technology Publications Inc.

Regian J.W., Shebilske W.L. & Monk J.M. (1992). Virtual reality: An instructional medium for visual-spatial tasks. Journal of Communications, Vol. 42, No. 4, pp. 136-149.

Rieber L.P. (1990). Using animation in science instruction with young children. *Journal of Educational Psychology*, Vol. 82, No. 1, pp. 135-140.

Rieber L.P. (1991). Effects of visual grouping strategies of computer animated presentations on selective attention in science. *Educational Technology Research and Development*, Vol. 39, No. 4, pp. 5-15.

Rieber L.P. (1992). Computer-based microworlds: A bridge between constructivism and direct instruction. *Educational Technology Research and Development*, Vol. 40, No. 1, pp. 93-106.

Rieber L.P. (1994). *Computers, Graphics and Learning.* Duuque, Iowa: WCB Brown & Benchmark.

Rieber L.P. (1995). A historical review of visualisation in human cognition. *Educational Technology, Research and Development.* Vol. 43, pp. 45-56.

Rieber L.P., Boyce M. & Assad C. (1990). The effects of computer animation on adult learning and retrieval tasks. *Journal of Computer-Based Instruction*, Vol. 17, No. 2, pp. 46-52.

Rose F.D. (2001). Learning and memory in virtual environments: A role in Neurorehabilitation? Questions (and Occasional Answers) from the University of East London. *Presence*, Vol. 10, No. 4, pp. 345-358.

Roussos M., Johnson A., Moher T., Leigh J., Vasilakis C. & Barnes C. (1999). Learning and building together in an immersive virtual world. *Presence*, Vol. 8, No. 3, pp. 247-263.

Ruddle R.A., Payne S.J. & Jones D.M. (1999). Navigating large-scale virtual environments: What differences occur between helmet-mounted and desk-top displays? *Presence*, Vol. 8, No. 2, pp. 157-168.

Rumbaugh D.M., Warner H., & Glasersfeld E. von (1978). Radical constructivism and Piaget's concept of knowledge. In F.B.Murray (Ed.), *The impact of Piagetian theory* (Pp. 109-122). Baltimore, MD: University Park Press.

Salisbury D. (1988). Effective drill and practice strategies. In Jonassen D. (Ed.), *Instructional designs for microcomputer courseware* (pp. 103-124). Hillsdale, NJ: Lawrence Earlbaum Associates.

Salzman M.C., Dede C., Loftin R.B. & Chen J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence*, Vol. 8, No. 3, pp. 293-316.

Samuels S. (1967). Attention process in reading: The effect of pictures on the acquisition of reading responses. *Journal of Educational Psychology*, Vol. 58, pp. 337-342.

Samuels S. (1970). Effects of pictures on learning to read, comprehension and attitudes. *Review of Educational Research*, Vol. 40, pp. 397-407.

Scaife M. & Rogers Y. (1996). External cognition: How do graphical representations work. *International Journal of Human-Computer Studies*, 45, pp. 185-213.

Schimmel B. (1988). Providing meaningful feedback in courseware. In Jonassen D. (Ed.), *Instructional designs for microcomputer courseware* (pp. 183-195). Hillsdale, NJ: Lawrence Earlbaum Associates.

Schlechtly P.C. (1990). *Schools for the 21st Century: Leadership imperatives for educational reform.* San Francisco, CA: Jossey-Bass.

Schunk D.H. & Gaa J.P. (1981). Goal-setting influence on learning and self-evaluation. *Journal of Classroom Interaction*, Vol. 16, No. 2, pp. 38-44.

Schwier R.A. (1995). Issues in emerging interactive technologies. In Anglin G.J. (Ed.), *Instructional technology: Past, present and future* (2nd Ed., pp. 131-142). Englewood, CO: Libraries Unlimited Inc.

Seng S.H. (1998). Teaching thinking skills for pre-service and in-service teachers in Singapore. *International Conference on Critical Thinking and Educational Reform.* (Zamboanga, Philipines), September 23-26.

Shepard R. (1967). Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behaviour*, Vol. 6, pp. 156-163.

Shimron J. (1975). Imagery and comprehension of prose by elementary school children. *Dissertation Abstracts International*, Vol. 36, 795-A.

Shneiderman B. (1983). Direct manipulating: A step beyond programming languages. *IEEE Computer*, Vol. 16, pp. 57-69.

Shultz T. R. & Lepper M. R. (1996). Cognitive dissonance reduction as constraint satisfaction. *Psychological Review*, 103, pp. 219-240.

Skinner B.F. (1938). *The behaviour of organisms: An experimental analysis.* Englewood Cliffs, NJ: Prentice-Hall.

Skinner B.F. (1950). Are theories of learning necessary? *Psychological Review*, Vol. 57, pp. 193-216.

Skinner B.F. (1958). Reinforcement today. *American Psychologist*, Vol. 13, pp. 94-99.

Skinner B. F. (1974). *About behaviourism.* NY: Knopf.
Slythe R. (1970). *The art of illustration 1750-1900.* London: The Library Association.

Snowman J. (1986). Learning tactics and strategies. In Phye G.D. & Andre T.(Eds.), *Cognitive classroom learning: Understanding, thinking and problem solving* (pp. 243-275). CA: Academic Press Inc.

Spiro R.J., Feltovich P.J., Jacobson M.J. & Coulson R.L. (1991). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational Technology*, Vol. 31, May, pp. 24-33.

Standing L., Conezio J. & Haber R. (1970). Perception and memory for pictures: Single trial learning of 2500 visual stimuli. *Psychonomic Science*, Vol. 19, pp. 73-74.

Stenning K. & Oberlander J. (1995). A cognitive theory of graphical and linguistic reasoning: Logic and implementation. *Cognitive Science,* 19, pp. 97-140.

Sternberg R.J. & Davidson J.E. (1983). Insight in the gifted. *Educational Psychologist,* Vol. 18, pp. 52-58.

Strenio A.J. (1981). *The testing trap.* NY: Wawson, Wade.

Stuart R. & Thomas J.C. (1991). The implications of education in cyberspace. *Multimedia Review*, Vol. 2, pp. 17-27.

Sutherland I. (1965). The ultimate display. *Proceedings of the IFIP Congress*, Vol. 2, pp. 506-508.

Szetela W. & Nicol C. (1992). Evaluating problem solving in mathematics. *Educational Leadership*, Vol. 49, No. 8, pp. 42-45.

Tan H.S. (2000). Virtual Training Environments, *Proceedings of Asia Pacific Advanced Network Conference 2000,* Beijing, pp.363-368.

Tan H.S. & Chu L. (2000). Remote Sharing of Operation and Training Environments (RESONATE), *Proceedings of the 6th International Conference on Modern Industrial Training*, Beijing, pp. 243-249.

Tan H.S. & Ward M.D. (1998). Virtual CIM system: A reality in CIM training, *Proceedings of Virtual Reality Technology and Internet Applications (VRTIA'98)*, Singapore, pp. 2.1-2.10.
Ref:
http://cvd.tp.edu.sg/publications/resonate/vrcim.pdf

Tan H.S., Zhu H.B. & Zhou H. (2002), V.O.L.U.M.E.: A Web-Centric Database System for Building Interactive 3D Constructivist Learning Environments, *Temasek Engineering Journal*, Vol. I, pp. 3-8.

Teo C.H. (1997). *Opening New Frontiers in Education with Information Technology*, Speech by Rear Admiral Teo Chee Hean, Minister for Education and 2nd Minister for Defence at the Launch of the Masterplan for IT in Education on Monday 28th April, 1997 at SUNTEC City at 1000hrs.
Ref:
http://www1.moe.edu.sg/iteducation/masterplan/speech.htm

Thompson B. (1998). In praise of brilliance: Where the praise really belongs. *American Psychologist*, 53, pp. 799-800.

Thompson B. and Snyder P.A. (1997). Statistical significance testing practices in the Journal of Experimental Education.

Journal of Experimental Education, 66, pp. 75-83.

Thorndike E.L. (1913). *Educational psychology. Vol. II. The psychology of learning.* NY: Teachers College, Columbia University.

Thurow L. (1999). *Building wealth: The new rules for individuals, companies and nations.* NY: Harper Collins.

Tobias S. (1987). Learner characteristics. In Gagné R. (Ed.), *Instructional technology: foundations* (pp. 207-232). Hillsdale, NJ: Lawrence Erlbaum Associates.

Tolman E.C. (1948). Cognitive maps in rats and men. *Psychological Review*, Vol. 55, No. 4, pp. 189-208.

Tucker M & Codding J. (1998). *Standards for our schools: How to set them, measure them and reach them.* CA: Jossey-Bass.

Twigg, C.A. (1997). *The Need For A National Learning Infrastructure*. Paper presented for NLII-SHEEO Seminar on the Public Policy Implications of the Information Technology Revolution, Denver. Ref: http://www.educause.edu/nlii/keydocs/monograph.html.

Van Sommers P. (1984). *Drawing and cognition.* Cambridge, MA: Cambridge University Press.

Vygotsky L. (1962). *Thought and language.* MA: MIT Press.

Vygotsky L.S. (1978). *Mind in society.* Cambridge, MA: The MIT Press.

Vygotsky L.S. (1981). The genesis of higher mental functions. In Wertsch J.V. (Ed.), *The concept of activity in Soviet psychology* (pp. 165). NY: Sharpe.

Vyuk R. (1981). *Overview and critique of Piaget's genetic epistemology, 1965-1980.* NY: Academic Press.

Watson J.B. (1913). Psychology as the behaviourist views it. *Psychological Review*, Vol. 20, pp. 158-177.

Weiner B. (1979). A theory of motivation for some classroom experiences. *Journal of Educational Psychology*, Vol. 71, No. 1, pp. 3-25.

Weiner B. (1990). History of motivational research in education. *Journal of Educational Psychology*, Vol. 82, No. 4, pp. 616-622.

Wertheimer M. (1923). Untersuchungen zur Lehre von der Gestalt, II [Laws of organization in perceptual forms]. Psycholoche Forschung, 4, 301-350. Exerpts translated and reprinted in Ellis W.D. (Ed.), *A source book of Gestalt psychology* (pp. 71-88). New York: Harcourt, Brace and Co., 1939.

Wickens C.D. & Baker P. (1995). Cognitive issues in virtual reality. In Barfield W. & Furness T. (Eds.), *Virtual environments and advanced interface design* (pp. 515-541). NY: Oxford University Press.

Willows D.H. & Houghton H.A. (1987). *The psychology of illustration*, Vol. 1. NY: Springer.

Winn W., Hoffman H., Hollander A., Osberg K., Rose H. & Char P. (1999). Student-built virtual environments. *Presence*, Vol. 8, No. 3, pp. 283-292.

Winn, W.D. (1995). The virtual reality roving vehicle project. *Technological Horizons in Education*, Vol. 23, No. 5, pp. 70-74.

Winn, W.D. (1997). Learning in hyperspace. *The Potential of the Web Workshop' 97.* Ref: http://www.umuc.edu/ide/potentialweb97/winn.html.

Winn W.D. & Bricken W. (1992). Designing virtual worlds for use in mathematics education: The example of experiential algebra. Educational Technology, Vol. 32, No. 12, pp. 12-19.

Winn, W., Li T.Z. & Schill, D. (1991). Diagrams as aids to problem solving: Their role in facilitating search and computation. *Educational Technology, Research and Development*, vol. 39, no. 1, pp. 17-29.

Witmer B.G., Bailey J.H., Knerr B.W. & Parsons K.C. (1996). Virtual space and real-world spaces: Transfer of route knowledge. *International Journal of Human-Computer Studies*, Vol. 45, pp. 413-428.

Youngblut C. (1997). Educational Uses of Virtual Reality Technology. *VR in the Schools, Vol. 3, No. (1),* http://www.soe.ecu.edu/vr/vrits/3-1young.htm

Zimmerman B.J. (1990). Self-regulated learning and academic achievement: An overview. *Educational Psychologist*, Vol. 25, No. 1, pp. 3-17.

Znaniecki F. (1934). *The method of sociology.* NY: Farrar & Rinehart.

APPENDIX A

TEST QUESTIONS

TEMASEK POLYTECHNIC

TEMASEK ENGINEERING SCHOOL

AY 2000/2001 TERM TEST

DIPLOMA IN MECHATRONICS
YEAR 3/SEMESTER 2

COMPUTER INTEGRATED MANUFACTURING (E004051)
TIME ALLOWED : 1 HOUR

INSTRUCTIONS TO CANDIDATES

1. This paper consists of 3 pages (including cover page and all other appendices).

2. It is divided into 2 sections:
   Section A contains <u>**THREE**</u> (3) short questions each worth **20** marks.
   Section B contains <u>**ONE**</u> **(1)** long question worth **40** marks.

3. Follow the rules set out on the cover of your answer booklet.

4. Write your matriculation number on any graph paper or any other separate sheets that you attach to your answer booklet.

5. Answer <u>**ALL**</u> the questions in **Section A** and **B**.

6. Begin each question on a new page.

SECTION A

Question 1

a) Define Part Family as used in Group Technology. (2 marks)

b) List THREE (3) principle approaches used for Part Family formation. (6 marks)

c) Define Cellular Manufacturing. (3 marks)

d) Briefly explain the steps needed to successfully carry out a Cellular Manufacturing Implementation. (9 marks)

Question 2

a) Define Process Planning. (4 marks)

b) Compare the differences between Variant and Generative Techniques in Process Planning, clearly stating each of their advantages and disadvantages. (16 marks)

Question 3

a) List FIVE (5) main features of a Flexible Manufacturing System (FMS). (5 marks)

b) The table below shows a matrix of machining and tool life times (figures in brackets) in minutes for three parts X, Y, and Z, using the tools 1, 2, and 3 in an FMS.

Tool\Part	X	Y	Z
1	18 (220)	-	26 (130)
2	-	32 (260)	20 (140)
3	25 (190)	20 (120)	-

If the strategy of tool sharing is used, calculate the number of tools needed for the following production requirements in the FMS:

Production volume of $X = 15$,
$Y = 30$,
$Z = 35$.

(15 marks)

SECTION B

Question 4

Five video players with varying problems are awaiting service at a repair shop. The best estimates for the labour times involved and the promised dates (the number of days from today) are shown in the following table.

Model of Video Player	Estimated Labour Time (Days)	Promise Date (Days from now)
KVC	8	11
ONSOM	3	12
SONI	12	24
TEC	1	5
TELEF	6	11

a) Assuming that customers cannot pick up their video players early, develop separate schedules using the **SPT (Shortest Processing Time)** and **EDD (Earliest Due Date)** rules.

(20 marks)

b) For **EACH** schedule:

1) What is the average flow time?
2) What is the Average WIP inventory (in video players)?
3) What is the Average total inventory (in video players)?
4) What is the percentage of job past due?

(16 marks)

c) Which schedule minimizes the maximum past due days for any video player? Comment on the performance of the two rules relative to the above performance measures.

(4 marks)

APPENDIX B

SURVEY QUESTIONNAIRES

<u>Evaluation of Virtual Reality (VR)/Virtual Environment (VE) Training</u>

The purpose of this questionnaire is to gather information regarding the effectiveness of using VR/VE in learning. Your constructive feedback will be used in a research in the use of VR/VE for education. At no time will your personal information be released. Thank you for your contribution.

Important Instructions **Mark heavy black marks that fill the circle completely like this:** **Correct** ●   **Wrong** ⊗ ⦶

Name:

Group I

For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
1. The system made the objectives very clear.	O	O	O	O
2. The system forced me to set intermediate goals in arriving at the solution.	O	O	O	O
3. The system helped me to break my goals into activities.	O	O	O	O
4. The system helped me to recognise the tasks and activities I need to perform.	O	O	O	O
5. The structure helped me to mentally visualise each activity before programming it.	O	O	O	O
6. The system allowed me to test each activity before moving on to the next.	O	O	O	O
7. I was easily able to find out where the mistakes were and to correct them.	O	O	O	O
8. The system helped me to look back and reflect on what I had done in order to proceed.	O	O	O	O
9. I modified, evolved my solution along the way.	O	O	O	O
10. The system helped me to plan to reach the solution.	O	O	O	O
11. I would be able to use the same method learnt in VR/VE for other problems.	O	O	O	O
12. The system captured my attention and fostered active involvement.	O	O	O	O
13. The system allowed me to try out different ideas.	O	O	O	O

For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
14. I prefer getting information directly from lessons rather than having to interact with the VR/VE system.	O	O	O	O
15. I could interact with the VR/VE objects and get an instant feedback.	O	O	O	O
16. From my previous experience in the course, I feel that I would learn better by testing my solutions with my instructor and friends rather than on the computer.	O	O	O	O
17. The instructor helped me more at the beginning than at the end.	O	O	O	O
18. Most of the time I did not miss face to face contact with the instructor in answering questions.	O	O	O	O
19. I think that getting familiar with the new user interface using VR/VE will be an obstacle to learning.	O	O	O	O
20. I was able to solve problems with practically no help at the end.	O	O	O	O
21. I found it difficult to use the VR system to arrive at a solution.	O	O	O	O
22. I learnt faster in a VR environment compared to traditional methods.	O	O	O	O
23. I absorbed more information using VR as a learning tool.	O	O	O	O
24. There were times when the environment became a reality.	O	O	O	O
25. I felt as if I was manipulating and running the actual system when I enter the environment.	O	O	O	O
26. I discussed how to solve problems with my coursemates.	O	O	O	O
27. I was able to reach a good solution faster after discussion with my coursemates.	O	O	O	O

For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
28. I think I would have found learning more enjoyable with the traditional method.	O	O	O	O
29. Using VR/VE as a learning tool makes learning harder.	O	O	O	O
30. I found that VR caused discomfort and disorientation when learning.	O	O	O	O
31. I would like to experience using VR/VE for other subjects	O	O	O	O
32. Based on my previous experience in the course, I might have learned more if the module had used the traditional approach..	O	O	O	O
33. Based on my experience in the first and second year of the course, I found that learning using VR/VE was more difficult and painful.	O	O	O	O

Please give your opinion in the following questions.

34. How did you feel about learning a task through a VR environment?

____

____

____

____

35. What was the one thing you least liked about learning from a VR environment?

____

____

____

____

36. What was the one thing you liked best about learning from a VR environment?

____

____

____

____

37. Number in increasing order of importance (1 being most important and 6 being the least), the aspect of VR which you find most helpful in your learning.

Aspects of VR/VE	Order
Encouraged me to plan my strategy in reaching the goal.(Self-directed activity)	
Captured my attention and fostered active involvement. (Motivation)	
Allowed me to try out different ideas and test them (Role of play)	
I could directly interact with the objects naturally in VR/VE (Natural semantics)	
I could interact with the VR/VE objects and get an instant feedback (Interactivity)	
VR/VE enabled me to test my solution without endangering myself (Safe space)	

38. Show the strategy you adopt when problem solving in the VR environment in order to arrive at a solution.

(You can use a sketch if necessary)

Evaluation of Virtual Reality (VR)/Virtual Environment (VE) Training and Traditional Methodology

The purpose of this questionnaire is to gather information regarding the effectiveness of using VR/VE in learning. Your constructive feedback will be used in a research in the use of VR/VE for education. At no time will your personal information be released. Thank you for your contribution.

Important Instructions

Mark heavy black marks that fill the circle completely like this:

Correct	**Wrong**
●	⊗ ⦶

Name:

Group II

	For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
1.	The objectives of the topic were defined clearly in the lesson.	O	O	O	O
2.	The structure of the lesson forced me to set intermediate goals in arriving at the solution.	O	O	O	O
3.	The structure of the lesson helped me to break my goals into activities.	O	O	O	O
4.	The structure of the lesson helped me to recognise the tasks and activities I need to perform.	O	O	O	O
5.	The structure of the lesson helped me to mentally visualise each activity of the topic under discussion.	O	O	O	O
6.	The structure of the lesson allowed me to test each activity before moving on to the next.	O	O	O	O
7.	I was able to easily find out where I made mistakes and correct them during the lesson.	O	O	O	O
8.	The structure of the lesson helped me to look back and reflect on what I had done in order to proceed.	O	O	O	O
9.	I modified, evolved my mental model of the topic along the way.	O	O	O	O
10.	The structure of the lesson helped me to plan to understand the topic under discussion.	O	O	O	O
11.	I will be able to use the same method learnt during class for other problems.	O	O	O	O
12.	The structure of the lesson captured my attention and fostered active involvement.	O	O	O	O

	For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
13.	The structure of the lesson allowed me to try out different ideas.	O	O	O	O
14.	I would have liked to have tried learning from interacting with information directly as in a VR/VE system.	O	O	O	O
15.	The structure of the lesson allowed me to easily get feedback instantly through my own effort.	O	O	O	O
16.	I think that a VR/VE system would have enabled me to test my solution more successfully on the computer than was possible by talking to my instructor or friends.	O	O	O	O
17.	The instructor helped me more at the beginning than at the end.	O	O	O	O
18.	I often depended on face to face contact with my instructor to clarify questions on the topic.	O	O	O	O
19.	I think that getting familiar with the new user interface using VR/VE would be one of the obstacles to learning.	O	O	O	O
20.	I was able to understand the topic and solve problems with practically no help at the end of the module.	O	O	O	O
21.	I think that it would be difficult to use VR to arrive at a solution.	O	O	O	O
22.	I believe I learnt faster in a traditional environment compared to what I know of the VR Environment.	O	O	O	O
23.	I absorbed more information using the traditional method.	O	O	O	O
24.	There were times when the lesson became as real as the topic discussed.	O	O	O	O
25.	I felt that I was able to understand clearly the running of the actual system when the topic was discussed in lectures.	O	O	O	O
26.	I discussed how to solve problems with my coursemates.	O	O	O	O

For each of the statements below, make heavy black marks that fill the circle completely in the box which most accurately reflects your view.	Strongly Agree	Agree	Disagree	Strongly Disagree
27. I was able to reach a good solution faster after discussion with my coursemates.	O	O	O	O
28. I think I would have found learning more enjoyable with VR/VE.	O	O	O	O
29. Using VR/VE as a learning tool would make learning easier.	O	O	O	O
30. I feel that VR/VE would cause discomfort and disorientation during learning.	O	O	O	O
31. I would like to be able to use VR/VE for other subjects.	O	O	O	O
32. Based on my experience in the course, I think I might have learned more if the module had used VR/VE.	O	O	O	O
33. Based on what I know of VR/VE, I think that learning using the traditional method is more difficult and painful.	O	O	O	O

Please give your opinion in the following questions.

34. How did you feel about learning through the traditional environment?

____

____

____

____

35. What was the one thing you least liked about learning from a traditional environment?

____

____

____

____

36. What was the one thing you like best about learning from a traditional environment?

____

____

____

____

37. Number in increasing order of importance (1 being most important and 6 being the least), the aspect of classroom environment, which you find most helpful in your learning.

Aspects of Classroom Environment	Order
Safe & proven method of learning	
Easy face-to-face discussion	
Instructor on hand to assist	
Presentation Method	
Audio Visual Aids	
Good Instructor	

38. Show the strategy you adopt to enable you to understand the topic.

(You can use a sketch if necessary)

APPENDIX C

SUBJECTS' PRE-TEST EXAMINATION SCORE & ANALYSIS

T-Test: Comparison of Means of Group I & II

Notes

Output Created		06-OCT-2001 13:35:51
Comments		
Input	Data	D:\DATA\personnal\EdD\Thesis\Data\classverification2.sav
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	40
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on the cases with no missing or out-of-range data for any variable in the analysis.
Syntax		T-TEST GROUPS=group('I' 'II') /MISSING=ANALYSIS /VARIABLES=avemark /CRITERIA=CIN(.95) .
Resources	Elapsed Time	0:00:00.05

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
AVE. EXAM. MARKS	I	20	72.4650	5.3059	1.1864
	II	20	68.5750	7.2770	1.6272

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AVE. EXAM. MARKS	Equal variances assumed	.198	.659	1.932	38	.061	3.8900	2.0138	-.1867	7.9667
	Equal variances not assumed			1.932	34.751	.062	3.8900	2.0138	-.1993	7.9793

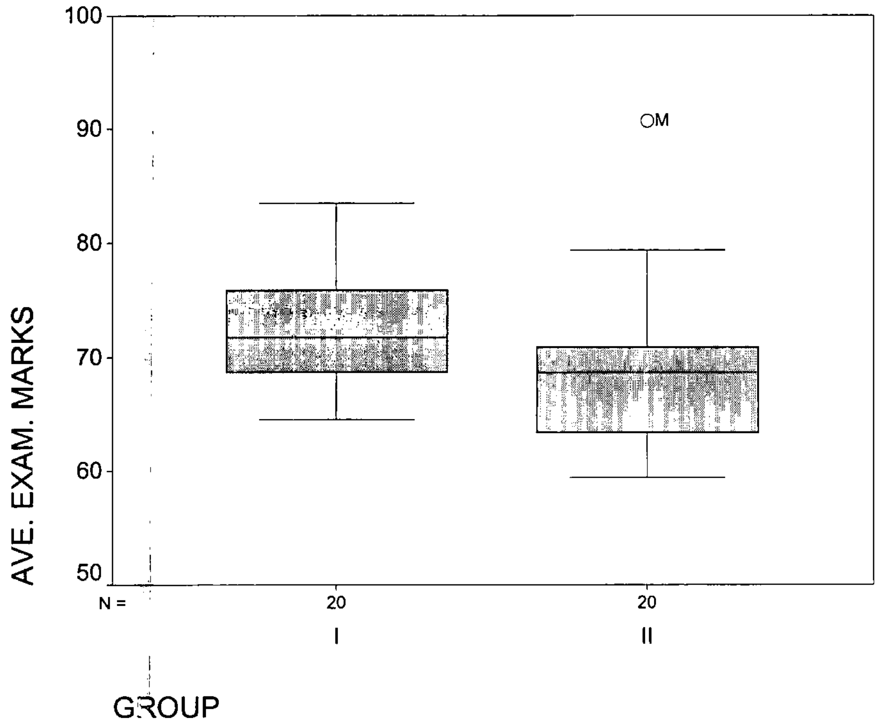
Explore

GROUP

Case Processing Summary

		Cases					
		Valid		Missing		Total	
	GROUP	N	Percent	N	Percent	N	Percent
AVE. EXAM. MARKS	I	20	100.0%	0	.0%	20	100.0%
	II	20	100.0%	0	.0%	20	100.0%

AVE. EXAM. MARKS



Summarize

Case Processing Summary[a]

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
AVE. EXAM. MARKS * GROUP	40	100.0%	0	.0%	40	100.0%

a. Limited to first 100 cases.

Case Summaries[a]

			AVE. EXAM. MARKS
GROUP	I	1		73.80
		2		78.00
		3		73.40
		4		66.00
		5		67.10
		6		83.50
		7		70.80
		8		69.10
		9		72.70
		10		80.70
		11		69.90
		12		68.80
		13		69.20
		14		79.50
		15		68.60
		16		75.30
		17		75.30
		18		76.60
		19		66.50
		20		64.50
		Total	N	20
			Mean	72.4650
			Median	71.7500
			Std. Error of Mean	1.1864
			Sum	1449.30
			Minimum	64.50
			Maximum	83.50
			Range	19.00
			Std. Deviation	5.3059
			Variance	28.153

Case Summaries[a]

				AVE. EXAM. MARKS
GROUP	II	1		69.00
		2		60.00
		3		79.40
		4		73.30
		5		90.70
		6		71.30
		7		63.70
		8		68.90
		9		59.40
		10		68.60
		11		63.50
		12		66.80
		13		68.70
		14		73.40
		15		62.20
		16		61.00
		17		70.60
		18		67.40
		19		70.40
		20		63.20
		Total	N	20
			Mean	68.5750
			Median	68.6500
			Std. Error of Mean	1.6272
			Sum	1371.50
			Minimum	59.40
			Maximum	90.70
			Range	31.30
			Std. Deviation	7.2770
			Variance	52.955

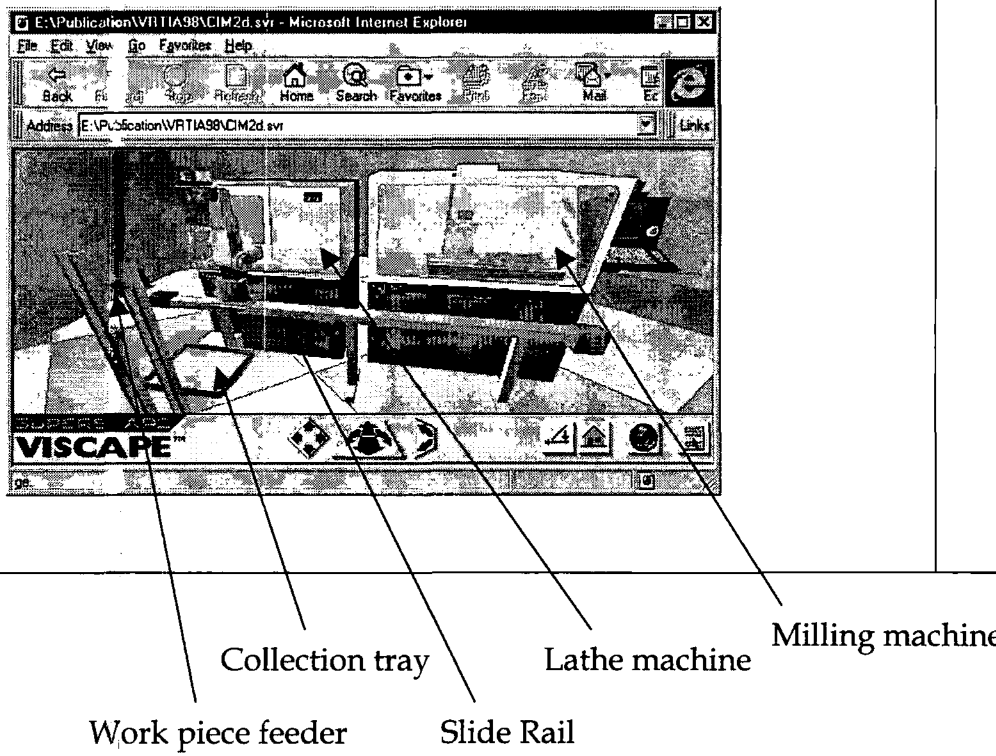
Case Summaries[a]

			AVE. EXAM. MARKS
GROUP	Total	N	40
		Mean	70.5200
		Median	69.1500
		Std. Error of Mean	1.0416
		Sum	2820.80
		Minimum	59.40
		Maximum	90.70
		Range	31.30
		Std. Deviation	6.5874
		Variance	43.394

a. Limited to first 100 cases.

APPENDIX D

SCREEN CAPTURES OF VIRTUAL ENVIRONMENT

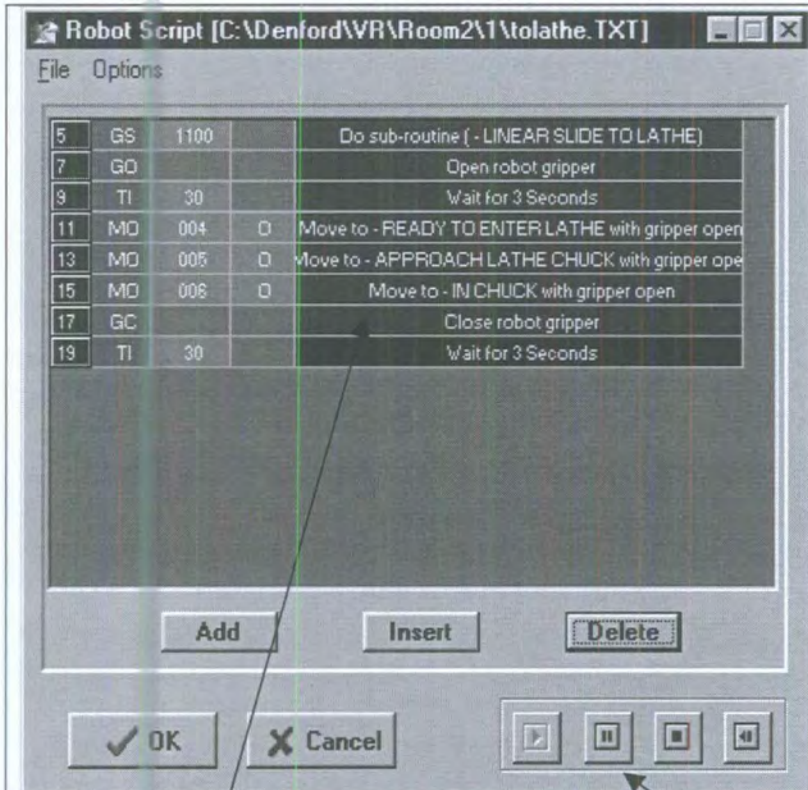


1. Screen capture of a VE, which consists of a robot, a slide rail, a lathe machine, a milling machine, a work piece feeder and a collection tray for finished parts.

Teach pendant

Robot dialogue box

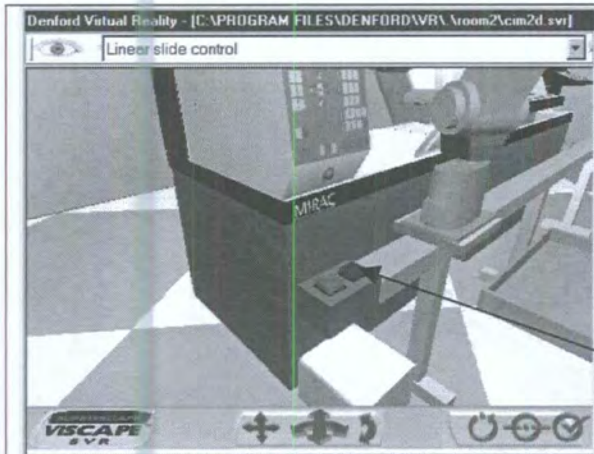
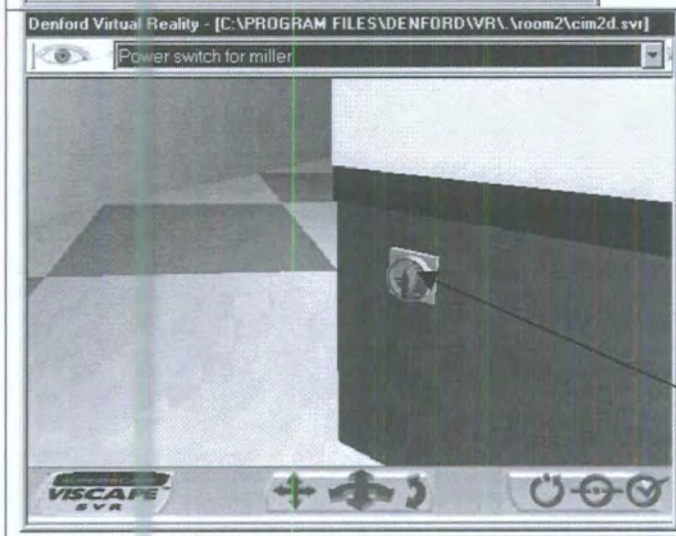
1. This screen capture shows how the robot is programmed. This procedure is modelled after actual programming techniques in real robots.
2. The teach pendant is used to teach the robot to move to positions for grasping and releasing parts.
3. The robot dialogue box is used to enter program instructions to the robot.



1. The robot dialogue box allows students to test each step of their program by incorporating Play, Pause, Stop & Rewind functions.
2. Students are thus able to test effectiveness of their programs easily.

Sample robot program developed by a student

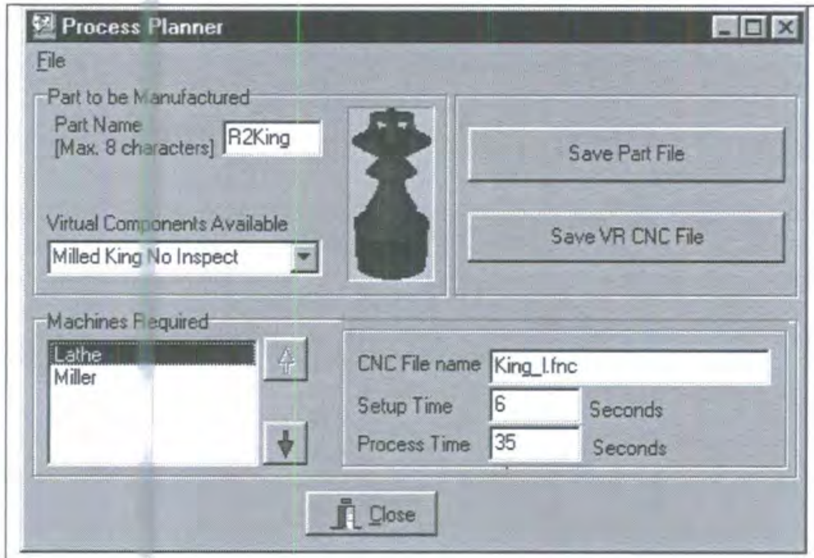
Play, Pause, Stop & Rewind buttons allows the student to test each step of the program

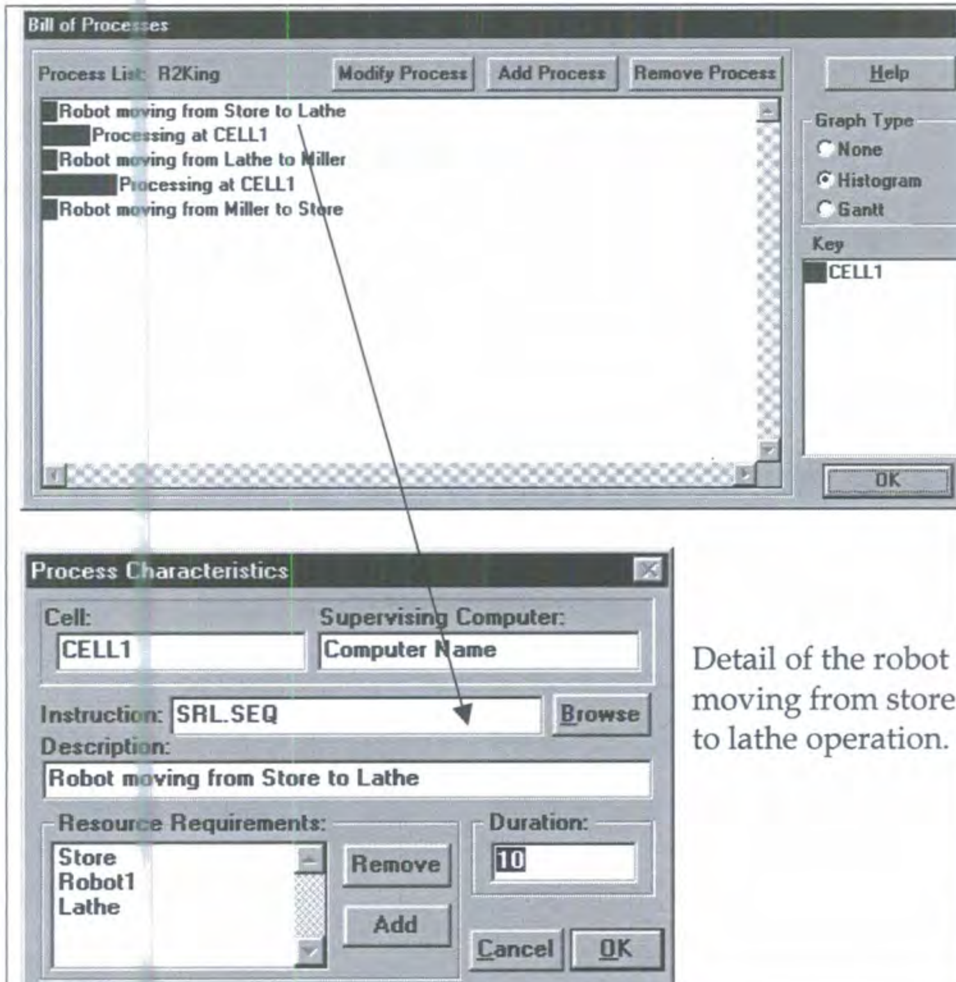
 Slide rail control buttons	1. The two slide rail control buttons are used to move the robot to the front of the lathe and milling machine respectively.
 Power switch	1. Every machine has a power switch. Each switch must be switched to the "on" position for the machine to be operational.

Play, Pause, Stop & Rewind buttons

Sample cell controller program developed by a student

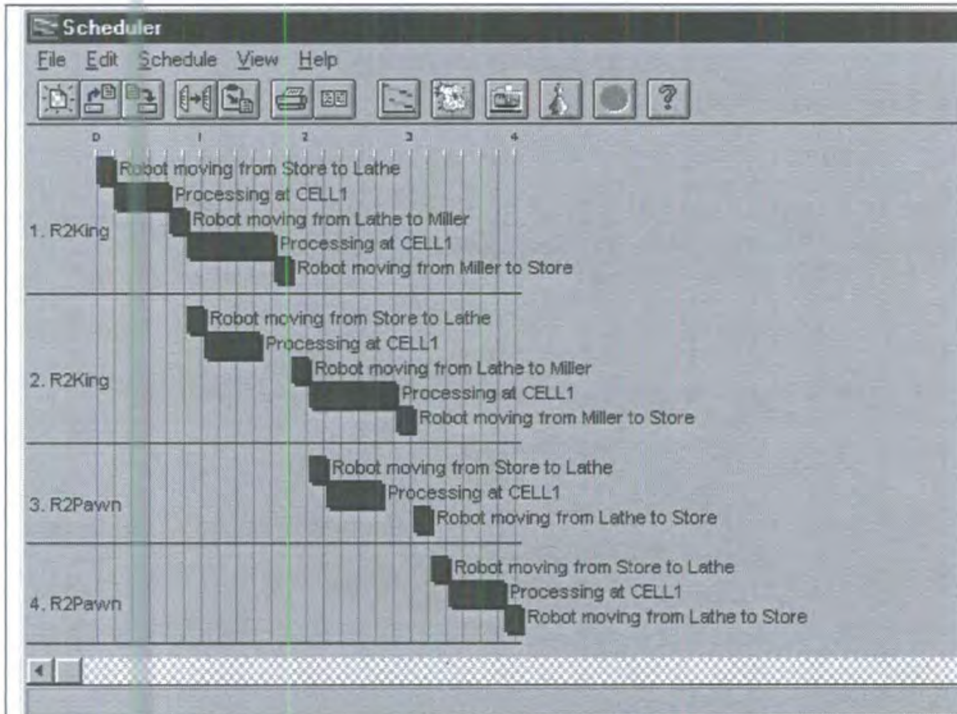
1. The cell controller dialogue box allows programming of the coordination activities between the machines in the machine workcell.
2. In the student example on the left, the cell controller first commands Robot1 to invoke its "Setup" program. It then informs the Lathe machine to open its chuck jaws to prepare for work piece loading. Robot1 is then told to invoke its "Loadlathe" program after which the Lathe machine is told to close its chuck jaws to grip the work piece. The cell controller then informs Robot1 to invoke its "Leavelathe" program to move out of the way before the lathe machine starts cutting.
3. The student can similarly use the Play, Pause, Stop & Rewind functions located at the bottom of the dialogue box to test the program. The program can then be modified as necessary.

	1. This is the process planner dialogue box. It allows the students to choose a work piece to be manufactured. Each work piece has its own associated manufacturing process. 2. Each process is in turn dependent on a particular machine. 3. The example on the left shows a "King" chess work piece. This work piece needs to be processed by two machines, the Lathe machine followed by the Milling machine.



Detail of the robot moving from store to lathe operation.

1. The Bill of Process allows the students to group the machines into a manufacturing cell to make the work piece and to allocate the sequence of operation.
2. This is generated after the process planner is completed.
3. Each process can be drilled down to show the detail of its relationship to the cell controller program.



1. The scheduler program is the final step. This scheduler uses the bill of process and the number of work pieces required to produce the work schedule.
2. This schedule is then sent to the cell controller (in the VE) to begin the manufacturing process.

APPENDIX E

SAMPLE OF TUTORIAL QUESTIONS

Temasek Polytechnic
School of Engineering
Computer Integrated Manufacturing
Tutorial 4 (MIS, CAPP and Scheduling)

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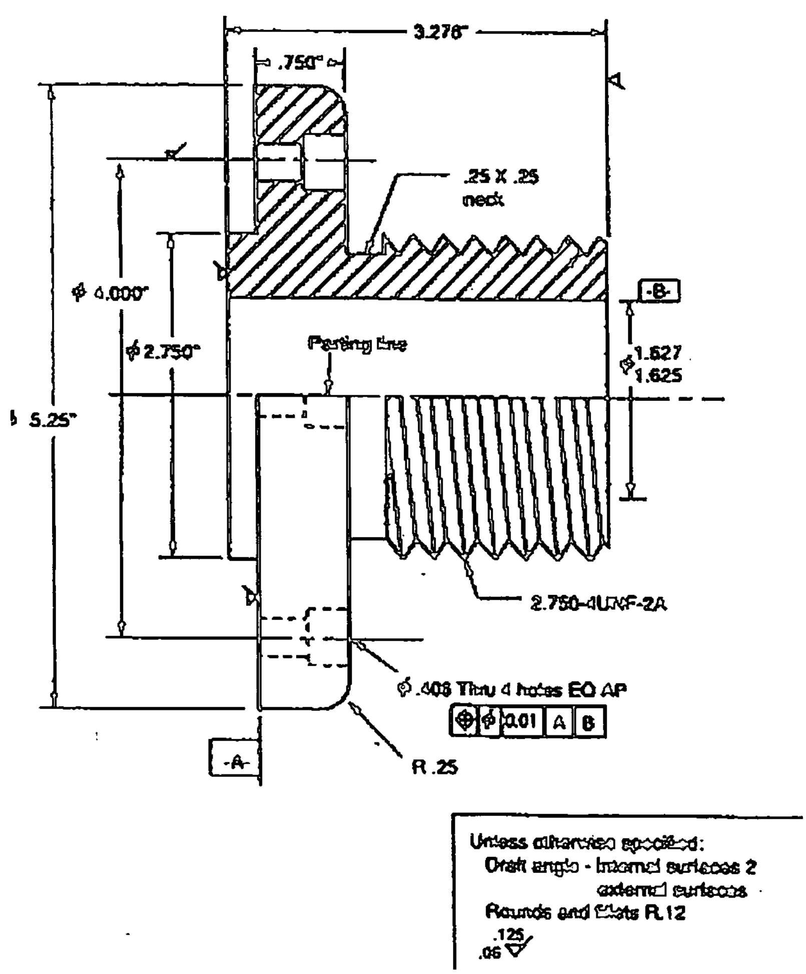
1. Short Questions:
   a. Define Production Activity Control.
   b. Explain what you understand by the term "Process Decoupling" and "Product Forcus" in terms of degree of complexity of PPC Systems.

2. Describe the use of Process Planning.

3. Compare the differences between Variant and Generative Techniques in Process Planning.

4. Five pieces of the part in the figure have been ordered. Prepare a process plan for the part.



5. What is the Relationship between Process Planning and Scheduling?

6. The Neptune's Den machine Shop specializes in overhauling outboard marine motors. Some motors require replacement of broken parts, whereas others need a complete overhaul. Currently, five motors with varying problems are awaiting service. The best estimates for the labour times involved and the promised dates (the number of days from today) are shown in the following table. Customers usually do not pick up their motors early.

Motor	Estimated Labour Time (days)	Promise Date (days from now)
50-hp Evinrude	5	8
7-hp Chrysler	4	15
100-hp Mercury	10	12
4-hp Sportsman	1	20
75-hp Nautique	3	10

a. Develop separate schedules using the SPT and EDD rules.

   i. What is the average flow time for each schedule?
   ii. What is the percentage of past due jobs for each schedule?
   iii. Which schedule minimizes the maximum past due days for any motor?

b. For each schedule in part (a), calculate

   i. average WIP inventory (in motors)
   ii. average total inventory (in motors)

7. The following data were reported by the shop floor control system for order processing at the edge grinder. The current date is week 150. The number of remaining operations and the total work remaining include the operation at the edge grinder. All orders are available for processing, and none have been started yet.

Current Order	Process Time (hr)	Due Date (wk)	Remaining Operations	Total Work Remaining (wks)
A101	10	162	10	9
B272	7	158	9	6
C105	15	152	1	1
D707	4	170	8	18
E555	8	154	5	8

a. Specify the priorities for each job if the shop-floor control system uses
    i. slack per remaining operation (S/RO)
    ii. critical ratio (CR)

b. For each priority rule, calculate the average flow time per job at the edge grinder.

8. Tree top Airlines needs to schedule 10 aircraft of various designs for maintenance. For scheduling, it is convenient to think of two maintenance operations for each plane in the following sequence.

   Operation 1: Engine and flight systems ground check, replacing worn or damaged parts where necessary.

   Operation 2: Flight tests and final safety checks.

   Based on flight records and the specific design of each aircraft, management has estimated that each operation will require the following amount of time (in days).

Aircraft	Operation 1	Operation 2
1	3	1
2	4	4
3	3	2
4	6	1
5	1	2
6	3	6
7	2	4
8	4	8
9	8	2
10	1	1

   Suppose that one of management's objectives is to minimize the total time that all 10 aircraft go without maintenance. This objective can be translated as minimizing the makespan of the 10-aircraft fleet. First, find a schedule that minimizes the makespan. Then calculate the average job flow time on an aircraft through the two operations, assuming that all 10 aircraft are available for maintenance now. What is the total elapsed time for maintaining all 10 aircrafts?

Temasek Polytechnic
School of Engineering
Computer Integrated Manufacturing
Tutorial 5 (Flexible Manufacturing System)

1. What are the five main features of automated flexible manufacturing that an FMS and an FMC have in common?

2. What is the difference between Cellular Manufacturing and a Flexible Manufacturing Cell, or is there any difference at all?

3. An FMS is to be planned for machining of crankcases. A typical crankcase has a machining cycle time of 33.38 min. the production requirement is to produce 20,000 crankcases per year in two shifts of 8 hours on 360 days per year. The current experience made by the company with machine breakdowns and maintenance of similar equipment says that a utilisation of about 85% is realistic. How many machining centres are needed to meet the production requirement?

4. The table below shows a matrix of machining times and tool life times (figures in brackets) in minutes for four parts A, B, C and D, using the tools a, b, c, and d.

Tool\Part	A	B	C	D
a	8 (120)	-	16 (180)	13 (240)
b	-	22 (160)	10 (240)	15 (180)
c	15 (180)	10 (200)	-	5 (120)
d	10 (240)	5 (180)	15 (120)	6 (24)

In an FMS the strategy of tool sharing shall be used. Calculate the number of tools needed for the following production requirements.

Production volume A = 25
B = 10
C = 38
D = 30

APPENDIX F

POST-TEST SCORE ANALYSIS

T-Test: Total Test Score

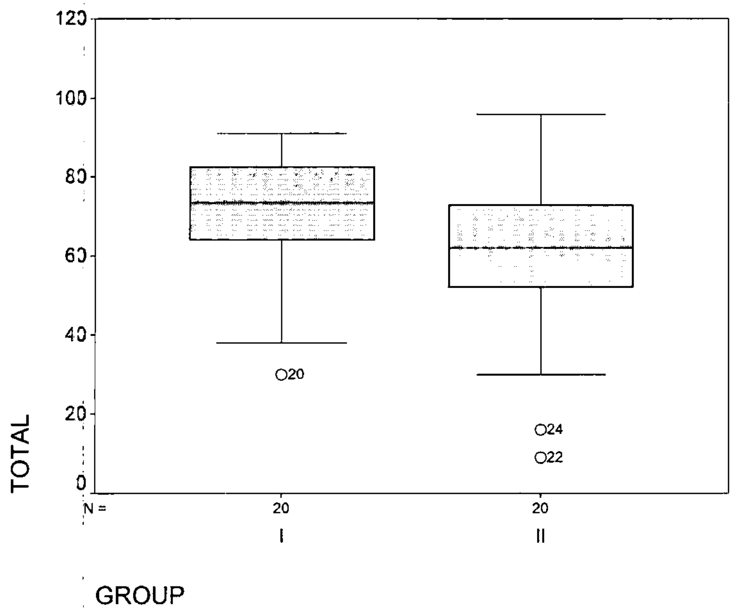
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
TOTAL	I	20	69.5500	17.3311	3.8753
	II	20	60.6000	22.5094	5.0333

Independent Samples Test of Group I vs Group II

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TOTAL	Equal variances assumed	.701	.408	1.409	38	.167	8.9500	6.3523	-3.9096	21.8096
	Equal variances not assumed			1.409	35.669	.168	8.9500	6.3523	-3.9373	21.8373

Box-Plot: Total Test Score



Summary: Total Test Score Analysis

Case Summaries[a]

			TOTAL
GROUP	I	1	68.00
		2	89.00
		3	84.00
		4	38.00
		5	76.00
		6	86.00
		7	76.00
		8	42.00
		9	52.00

Case Summaries[a]

				TOTAL
GROUP	I	10		89.00
		11		70.00
		12		81.00
		13		71.00
		14		91.00
		15		67.00
		16		76.00
		17		76.00
		18		68.00
		19		61.00
		20		30.00
		Total	N	20
			Mean	69.5500
			Median	73.5000
			Sum	1391.00
			Minimum	30.00
			Maximum	91.00
			Range	61.00
			Std. Deviation	17.3311
			Variance	300.366

Case Summaries[a]

				TOTAL
GROUP	II	1		53.00
		2		9.00
		3		58.00
		4		16.00
		5		96.00
		6		64.00
		7		30.00
		8		58.00
		9		46.00
		10		51.00
		11		90.00
		12		86.00
		13		77.00
		14		74.00
		15		60.00
		16		60.00
		17		71.00
		18		72.00
		19		72.00
		20		69.00
		Total	N	20
			Mean	60.6000
			Median	62.0000
			Sum	1212.00
			Minimum	9.00
			Maximum	96.00
			Range	87.00
			Std. Deviation	22.5094
			Variance	506.674

Case Summaries[a]

			TOTAL
GROUP	Total	N	40
		Mean	65.0750
		Median	69.5000
		Sum	2603.00
		Minimum	9.00
		Maximum	96.00
		Range	87.00
		Std. Deviation	20.3399
		Variance	413.712

a. Limited to first 100 cases.

T-Test: Question 1 Score

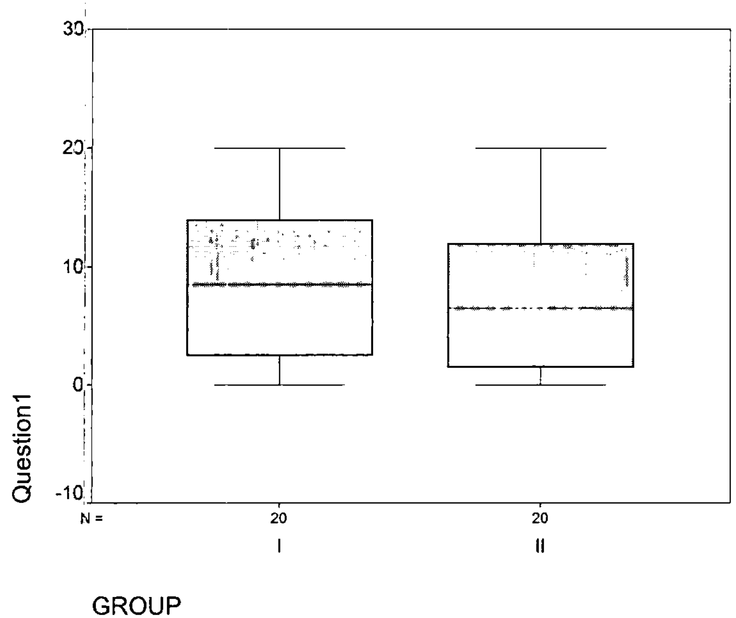
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Question1	I	20	8.650	6.792	1.519
	II	20	7.350	6.063	1.356

Independent Samples Test of Group I vs Group II

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Question1	Equal variances assumed	.808	.374	.639	38	.527	1.300	2.036	-2.822	5.422
	Equal variances not assumed			.639	37.521	.527	1.300	2.036	-2.823	5.423

Box-Plot: Question1 Score



Summary: Question 1 Score Analysis

Case Summaries[a]

			Question1
GROUP	I	1	8.0
		2	16.0
		3	16.0
		4	.0

Case Summaries[a]

			Question1
GROUP	I	5	4.0
		6	14.0
		7	4.0
		8	1.0
		9	9.0
		10	13.0
		11	6.0
		12	10.0
		13	4.0
		14	13.0
		15	.0
		16	14.0
		17	20.0
		18	20.0
		19	1.0
		20	.0
		Total N	20
		Mean	8.650
		Median	8.500
		Sum	173.0
		Minimum	.0
		Maximum	20.0
		Range	20.0
		Std. Deviation	6.792
		Variance	46.134

Case Summaries[a]

				Question1
GROUP	II	1		1.0
		2		1.0
		3		7.0
		4		.0
		5		20.0
		6		9.0
		7		2.0
		8		7.0
		9		.0
		10		6.0
		11		18.0
		12		14.0
		13		13.0
		14		14.0
		15		5.0
		16		9.0
		17		11.0
		18		6.0
		19		1.0
		20		3.0
		Total	N	20
			Mean	7.350
			Median	6.500
			Sum	147.0
			Minimum	.0
			Maximum	20.0
			Range	20.0
			Std. Deviation	6.063
			Variance	36.766

Case Summaries[a]

			Question1
GROUP	Total	N	40
		Mean	8.000
		Median	7.000
		Sum	320.0
		Minimum	.0
		Maximum	20.0
		Range	20.0
		Std. Deviation	6.389
		Variance	40.821

a. Limited to first 100 cases.

T-Test: Question 2 Score

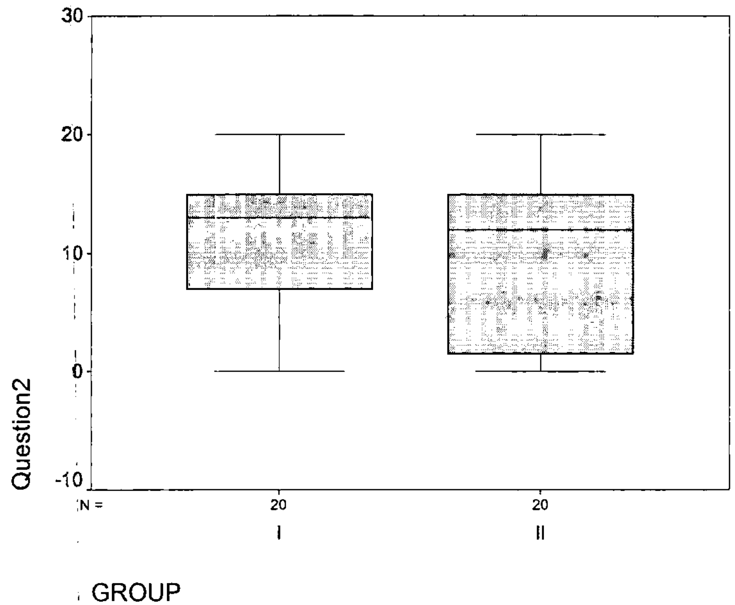
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Question2	I	20	11.300	6.001	1.342
	II	20	9.250	7.181	1.606

Independent Samples Test of Group I vs Group II

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Question2	Equal variances assumed	2.581	.116	.980	38	.333	2.050	2.093	-2.186	6.286
	Equal variances not assumed			.980	36.838	.334	2.050	2.093	-2.191	6.291

Box-Plot: Question2 Score



Summary: Question 2 Score Analysis

Case Summaries[a]

			Question2
GROUP	I	1	12.0
		2	14.0
		3	14.0
		4	6.0

Case Summaries[a]

			Question2
GROUP I	5		14.0
	6		16.0
	7		16.0
	8		.0
	9		4.0
	10		18.0
	11		9.0
	12		20.0
	13		12.0
	14		20.0
	15		14.0
	16		11.0
	17		14.0
	18		.0
	19		8.0
	20		4.0
	Total	N	20
		Mean	11.300
		Median	13.000
		Sum	226.0
		Minimum	.0
		Maximum	20.0
		Range	20.0
		Std. Deviation	6.001
		Variance	36.011

Case Summaries[a]

				Question2
GROUP	II	1		12.0
		2		.0
		3		14.0
		4		3.0
		5		16.0
		6		4.0
		7		.0
		8		18.0
		9		.0
		10		.0
		11		18.0
		12		17.0
		13		13.0
		14		8.0
		15		4.0
		16		.0
		17		14.0
		18		12.0
		19		20.0
		20		12.0
		Total	N	20
			Mean	9.250
			Median	12.000
			Sum	185.0
			Minimum	.0
			Maximum	20.0
			Range	20.0
			Std. Deviation	7.181
			Variance	51.566

Case Summaries[a]

			Question2
GROUP	Total	N	40
		Mean	10.275
		Median	12.000
		Sum	411.0
		Minimum	.0
		Maximum	20.0
		Range	20.0
		Std. Deviation	6.614
		Variance	43.743

a. Limited to first 100 cases.

T-Test: Question 3 Score

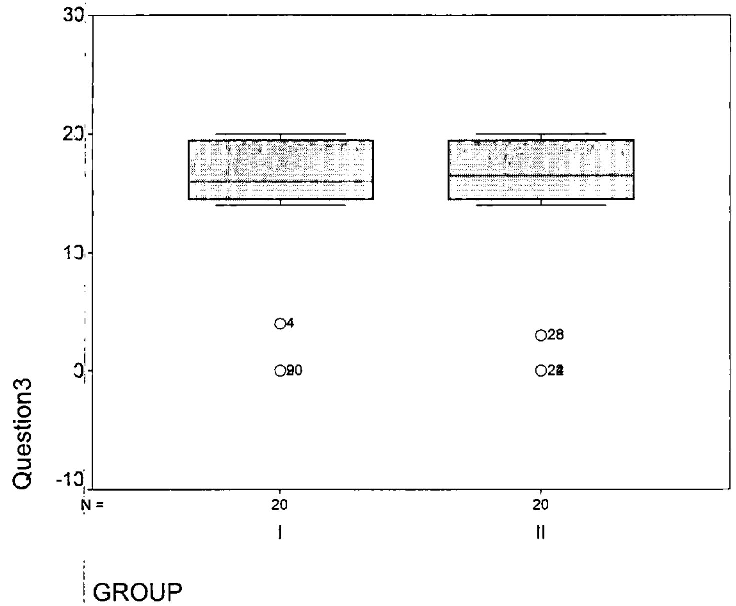
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Question3	I	20	14.850	6.268	1.402
	II	20	14.300	6.899	1.543

Independent Samples Test of Group I vs Group II

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Question3	Equal variances assumed	.426	.518	.264	38	.793	.550	2.084	-3.669	4.769
	Equal variances not assumed			.264	37.657	.793	.550	2.084	-3.671	4.771

Box-Plot: Question3 Score



Summary: Question 3 Score Analysis

Case Summaries[a]

			Question3
GROUP	I	1	14.0
		2	19.0
		3	17.0
		4	4.0

Case Summaries[a]

				Question3
GROUP	I	5		20.0
		6		20.0
		7		20.0
		8		15.0
		9		.0
		10		20.0
		11		15.0
		12		15.0
		13		17.0
		14		20.0
		15		15.0
		16		19.0
		17		15.0
		18		18.0
		19		14.0
		20		.0
		Total	N	20
			Mean	14.850
			Median	16.000
			Sum	297.0
			Minimum	.0
			Maximum	20.0
			Range	20.0
			Std. Deviation	6.268
			Variance	39.292

Case Summaries[a]

				Question3
GROUP	II	1		14.0
		2		.0
		3		3.0
		4		.0
		5		20.0
		6		15.0
		7		20.0
		8		3.0
		9		16.0
		10		17.0
		11		20.0
		12		20.0
		13		15.0
		14		17.0
		15		19.0
		16		15.0
		17		18.0
		18		20.0
		19		15.0
		20		19.0
		Total	N	20
			Mean	14.300
			Median	16.500
			Sum	286.0
			Minimum	.0
			Maximum	20.0
			Range	20.0
			Std. Deviation	6.899
			Variance	47.589

Case Summaries[a]

			Question3
GROUP	Total	N	40
		Mean	14.575
		Median	16.500
		Sum	583.0
		Minimum	.0
		Maximum	20.0
		Range	20.0
		Std. Deviation	6.512
		Variance	42.404

a. Limited to first 100 cases.

T-Test: Question 4 Score

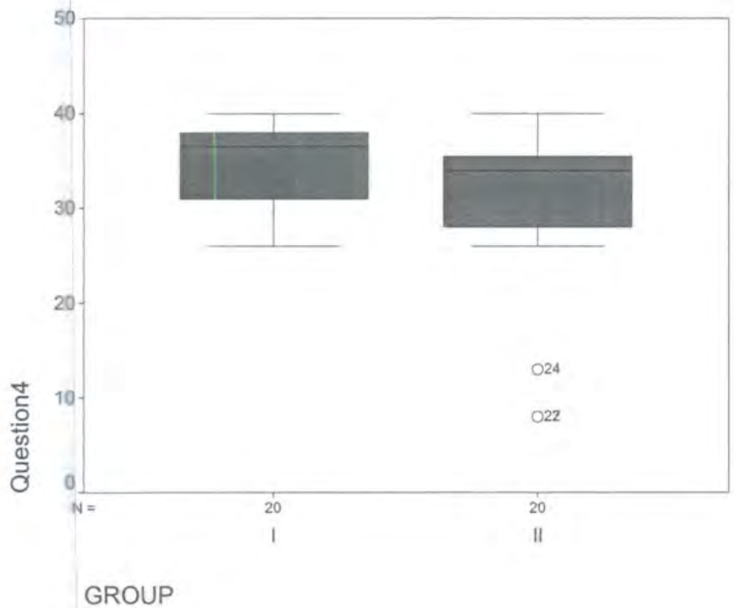
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Question4	I	20	34.750	4.789	1.071
	II	20	29.700	9.319	2.084

Independent Samples Test of Group I vs Group II

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Question4	Equal variances assumed	3.214	.081	2.155	38	.038	5.050	2.343	.307	9.793
	Equal variances not assumed			2.155	28.380	.040	5.050	2.343	.254	9.846

Box-Plot: Question 4 Score



Summary: Question 4 Score Analysis

Case Processing Summary[a]

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Question4 * GROUP	40	100.0%	0	.0%	40	100.0%

a. Limited to first 100 cases.

Case Summaries[a]

			Question4
GROUP	I	1	34.0
		2	40.0
		3	37.0
		4	28.0
		5	38.0
		6	36.0
		7	36.0
		8	26.0
		9	39.0
		10	38.0
		11	40.0
		12	36.0
		13	38.0
		14	38.0
		15	38.0
		16	32.0
		17	27.0
		18	30.0
		19	38.0
		20	26.0
		Total N	20
		Mean	34.750
		Median	36.500
		Sum	695.0
		Minimum	26.0
		Maximum	40.0
		Range	14.0
		Std. Deviation	4.789
		Variance	22.934

Case Summaries[a]

				Question4
GROUP	II	1		26.0
		2		8.0
		3		34.0
		4		13.0
		5		40.0
		6		36.0
		7		8.0
		8		30.0
		9		30.0
		10		28.0
		11		34.0
		12		35.0
		13		36.0
		14		35.0
		15		32.0
		16		36.0
		17		28.0
		18		34.0
		19		36.0
		20		35.0
		Total	N	20
			Mean	29.700
			Median	34.000
			Sum	594.0
			Minimum	8.0
			Maximum	40.0
			Range	32.0
			Std. Deviation	9.319
			Variance	86.853

Case Summaries[a]

			Question4
GROUP	Total	N	40
		Mean	32.225
		Median	35.000
		Sum	1289.0
		Minimum	8.0
		Maximum	40.0
		Range	32.0
		Std. Deviation	7.748
		Variance	60.025

a. Limited to first 100 cases.

APPENDIX G

QUESTIONNAIRE ANALYSIS

T-Test - Survey Q1

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q1	I	20	3.35	.49	.11
	II	20	2.85	.81	.18

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q1	Equal variances assumed	1.655	.206	2.357	38	.024	.50	.21	7.06E-02	.93
	Equal variances not assumed			2.357	31.176	.025	.50	.21	6.75E-02	.93

T-Test - Survey Q2

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q2	I	20	3.20	.41	9.18E-02
	II	20	2.50	.83	.18

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q2	Equal variances assumed	12.608	.001	3.390	38	.002	.70	.21	.28	1.12
	Equal variances not assumed			3.390	27.819	.002	.70	.21	.28	1.12

T-Test - Survey Q3

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q3	I	20	3.35	.59	.13
	II	20	2.70	.66	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q3	Equal variances assumed	.198	.659	3.299	38	.002	.65	.20	.25	1.05
	Equal variances not assumed			3.299	37.530	.002	.65	.20	.25	1.05

T-Test - Survey Q4

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q4	I	20	3.25	.44	9.93E-02
	II	20	2.80	.62	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q4	Equal variances assumed	1.187	.283	2.651	38	.012	.45	.17	.11	.79
	Equal variances not assumed			2.651	34.568	.012	.45	.17	.11	.79

T-Test - Survey Q5

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q5	I	20	3.30	.47	.11
	II	20	2.60	.60	.13

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q5	Equal variances assumed	1.841	.183	4.114	38	.000	.70	.17	.36	1.04
	Equal variances not assumed			4.114	35.989	.000	.70	.17	.35	1.05

T-Test - Survey Q6

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q6	I	20	3.50	.51	.11
	II	20	2.55	.76	.17

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q6	Equal variances assumed	3.420	.072	4.637	38	.000	.95	.20	.54	1.36
	Equal variances not assumed			4.637	33.358	.000	.95	.20	.53	1.37

T-Test - Survey Q7

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q7	I	20	3.10	.31	6.88E-02
	II	20	2.65	.49	.11

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q7	Equal variances assumed	18.404	.000	3.481	38	.001	.45	.13	.19	.71
	Equal variances not assumed			3.481	31.999	.001	.45	.13	.19	.71

T-Test - Survey Q8

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q8	I	20	3.00	.56	.13
	II	20	2.65	.67	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q8	Equal variances assumed	3.750	.060	1.789	38	.082	.35	.20	-4.61E-02	.75
	Equal variances not assumed			1.789	36.868	.082	.35	.20	-4.65E-02	.75

T-Test - Survey Q9

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q9	I	20	3.25	.44	9.93E-02
	II	20	2.85	.37	8.19E-02

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q9	Equal variances assumed	2.502	.122	3.107	38	.004	.40	.13	.14	.66
	Equal variances not assumed			3.107	36.670	.004	.40	.13	.14	.66

T-Test - Survey Q10

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q10	I	20	3.00	.46	.10
	II	20	2.50	.61	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q10	Equal variances assumed	11.217	.002	2.939	38	.006	.50	.17	.16	.84
	Equal variances not assumed			2.939	35.369	.006	.50	.17	.15	.85

T-Test - Survey Q11

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q11	I	20	3.25	.44	9.93E-02
	II	20	2.80	.52	.12

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q11	Equal variances assumed	.081	.778	2.932	38	.006	.45	.15	.14	.76
	Equal variances not assumed			2.932	37.028	.006	.45	.15	.14	.76

T-Test - Survey Q12

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q12	I	20	3.20	.52	.12
	II	20	2.65	.59	.13

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q12	Equal variances assumed	.821	.371	3.128	38	.003	.55	.18	.19	.91
	Equal variances not assumed			3.128	37.505	.003	.55	.18	.19	.91

T-Test - Survey Q13

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q13	I	20	3.05	.51	.11
	II	20	2.65	.67	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q13	Equal variances assumed	4.847	.034	2.122	38	.040	.40	.19	1.84E-02	.78
	Equal variances not assumed			2.122	35.477	.041	.40	.19	1.75E-02	.78

T-Test - Survey Q14

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q14	I	20	2.65	.75	.17
	II	20	2.75	.64	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q14	Equal variances assumed	.071	.791	-.456	38	.651	-.10	.22	-.54	.34
	Equal variances not assumed			-.456	37.131	.651	-.10	.22	-.54	.34

T-Test - Survey Q15

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q15	I	20	3.25	.44	9.93E-02
	II	20	2.60	.50	.11

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q15	Equal variances assumed	3.709	.062	4.333	38	.000	.65	.15	.35	.95
	Equal variances not assumed			4.333	37.435	.000	.65	.15	.35	.95

T-Test - Survey Q16

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q16	I	20	2.95	.69	.15
	II	20	2.35	.59	.13

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q16	Equal variances assumed	.014	.907	2.971	38	.005	.60	.20	.19	1.01
	Equal variances not assumed			2.971	37.110	.005	.60	.20	.19	1.01

T-Test - Survey Q17

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q17	I	20	3.10	.64	.14
	II	20	2.55	.69	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q17	Equal variances assumed	1.697	.201	2.620	38	.013	.55	.21	.12	.98
	Equal variances not assumed			2.620	37.822	.013	.55	.21	.12	.98

T-Test - Survey Q18

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q18	I	20	2.80	.41	9.18E-02
	II	20	1.55	.60	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q18	Equal variances assumed	9.796	.003	7.648	38	.000	1.25	.16	.92	1.58
	Equal variances not assumed			7.648	33.436	.000	1.25	.16	.92	1.58

T-Test - Survey Q19

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q19	I	20	2.70	.47	.11
	II	20	1.70	.66	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q19	Equal variances assumed	2.865	.099	5.536	38	.000	1.00	.18	.63	1.37
	Equal variances not assumed			5.536	34.418	.000	1.00	.18	.63	1.37

T-Test - Survey Q20

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q20	I	20	2.80	.52	.12
	II	20	1.90	.79	.18

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q20	Equal variances assumed	3.429	.072	4.255	38	.000	.90	.21	.47	1.33
	Equal variances not assumed			4.255	33.023	.000	.90	.21	.47	1.33

T-Test - Survey Q21

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q21	I	20	3.05	.22	5.00E-02
	II	20	1.75	.64	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q21	Equal variances assumed	23.366	.000	8.592	38	.000	1.30	.15	.99	1.61
	Equal variances not assumed			8.592	23.589	.000	1.30	.15	.99	1.61

T-Test - Survey Q22

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q22	I	20	2.95	.39	8.81E-02
	II	20	2.25	.79	.18

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q22	Equal variances assumed	18.371	.000	3.559	38	.001	.70	.20	.30	1.10
	Equal variances not assumed			3.559	27.975	.001	.70	.20	.30	1.10

T-Test - Survey Q23

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q23	I	20	3.00	.46	.10
	II	20	2.10	.72	.16

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q23	Equal variances assumed	6.128	.018	4.723	38	.000	.90	.19	.51	1.29
	Equal variances not assumed			4.723	32.295	.000	.90	.19	.51	1.29

T-Test - Survey Q24

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q24	I	20	3.00	.00	.00
	II	20	2.70	.47	.11

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q24	Equal variances assumed	99.750	.000	2.854	38	.007	.30	.11	8.72E-02	.51
	Equal variances not assumed			2.854	19.000	.010	.30	.11	8.00E-02	.52

T-Test - Survey Q25

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q25	I	20	3.05	.51	.11
	II	20	2.50	.61	.14

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q25	Equal variances assumed	6.241	.017	3.101	38	.004	.55	.18	.19	.91
	Equal variances not assumed			3.101	36.914	.004	.55	.18	.19	.91

T-Test - Survey Q26

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q26	I	20	3.20	.41	9.18E-02
	II	20	2.85	.67	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q26	Equal variances assumed	3.048	.089	1.990	38	.054	.35	.18	-5.98E-03	.71
	Equal variances not assumed			1.990	31.475	.055	.35	.18	-8.42E-03	.71

T-Test - Survey Q27

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q27	I	20	3.30	.47	.11
	II	20	2.85	.67	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q27	Equal variances assumed	.766	.387	2.457	38	.019	.45	.18	7.92E-02	.82
	Equal variances not assumed			2.457	34.038	.019	.45	.18	7.78E-02	.82

T-Test - Survey Q28

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q28	I	20	3.00	.56	.13
	II	20	2.70	.47	.11

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q28	Equal variances assumed	1.123	.296	1.831	38	.075	.30	.16	-3.17E-02	.63
	Equal variances not assumed			1.831	36.852	.075	.30	.16	-3.20E-02	.63

T-Test - Survey Q29

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q29	I	20	2.90	.45	.10
	II	20	2.45	.76	.17

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q29	Equal variances assumed	9.198	.004	2.284	38	.028	.45	.20	5.12E-02	.85
	Equal variances not assumed			2.284	30.770	.029	.45	.20	4.81E-02	.85

T-Test - Survey Q30

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q30	I	20	3.05	.22	5.00E-02
	II	20	2.80	.41	9.18E-02

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q30	Equal variances assumed	10.012	.003	2.392	38	.022	.25	.10	3.84E-02	.46
	Equal variances not assumed			2.392	29.368	.023	.25	.10	3.64E-02	.46

T-Test - Survey Q31

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q31	I	20	3.00	.65	.15
	II	20	2.70	.92	.21

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q31	Equal variances assumed	3.660	.063	1.189	38	.242	.30	.25	-.21	.81
	Equal variances not assumed			1.189	34.086	.243	.30	.25	-.21	.81

T-Test - Survey Q32

Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q32	I	20	2.85	.59	.13
	II	20	2.70	.66	.15

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q32	Equal variances assumed	1.423	.240	.761	38	.451	.15	.20	-.25	.55
	Equal variances not assumed			.761	37.530	.451	.15	.20	-.25	.55

T-Test - Survey Q33

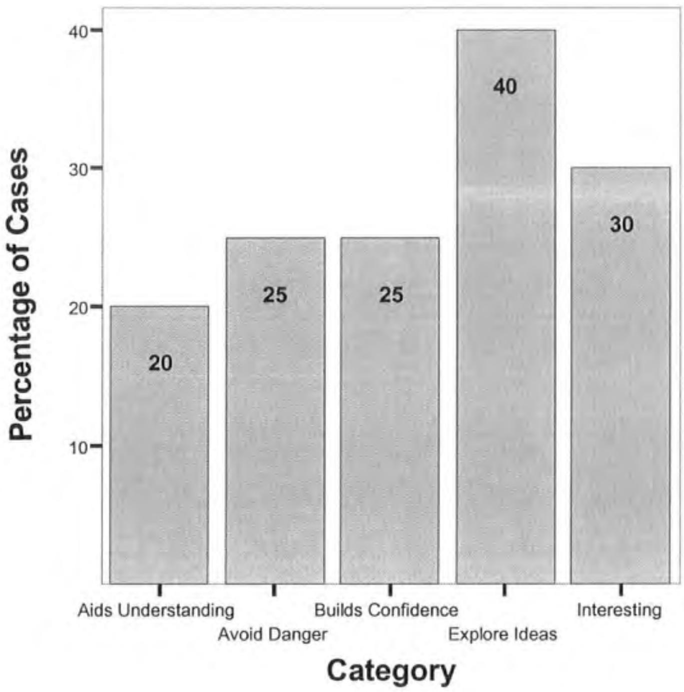
Group Statistics

	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Q33	I	20	3.20	.41	9.18E-02
	II	20	2.55	.51	.11

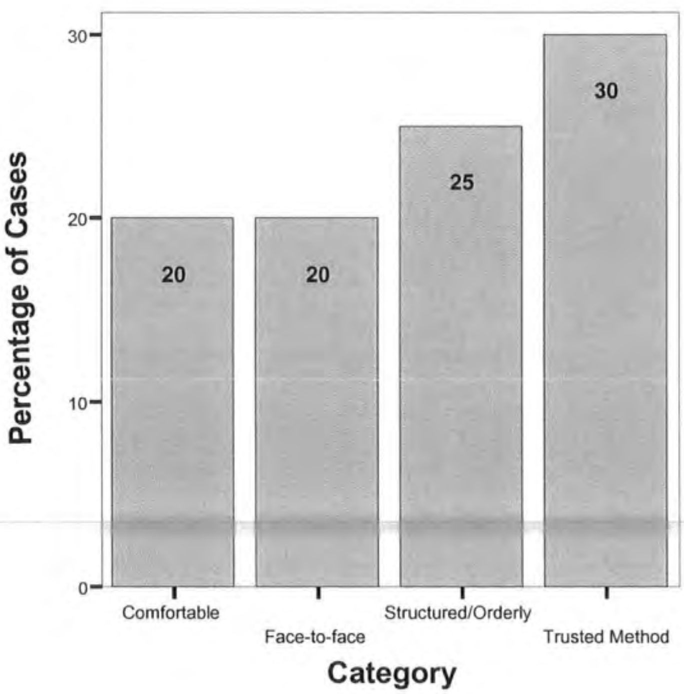
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Q33	Equal variances assumed	9.686	.004	4.438	38	.000	.65	.15	.35	.95
	Equal variances not assumed			4.438	36.325	.000	.65	.15	.35	.95

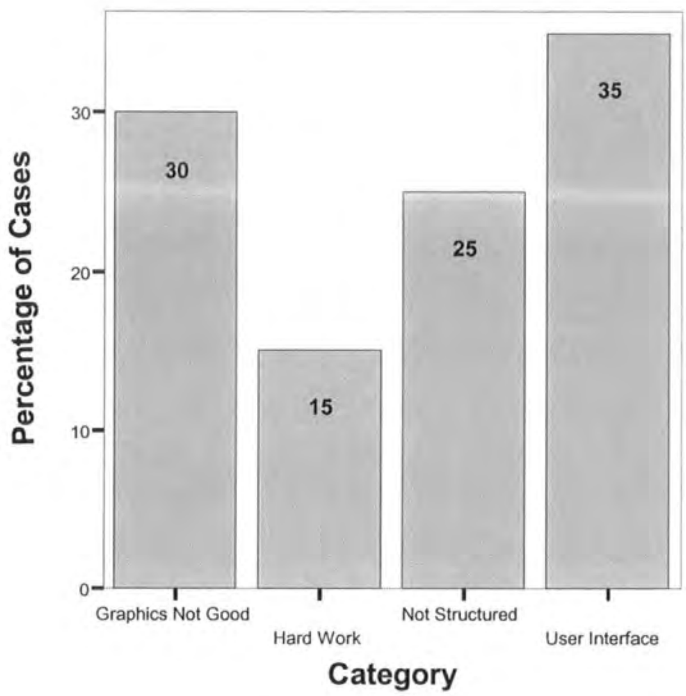
Bar Chart of Percentage of Cases - Group I, Question 34



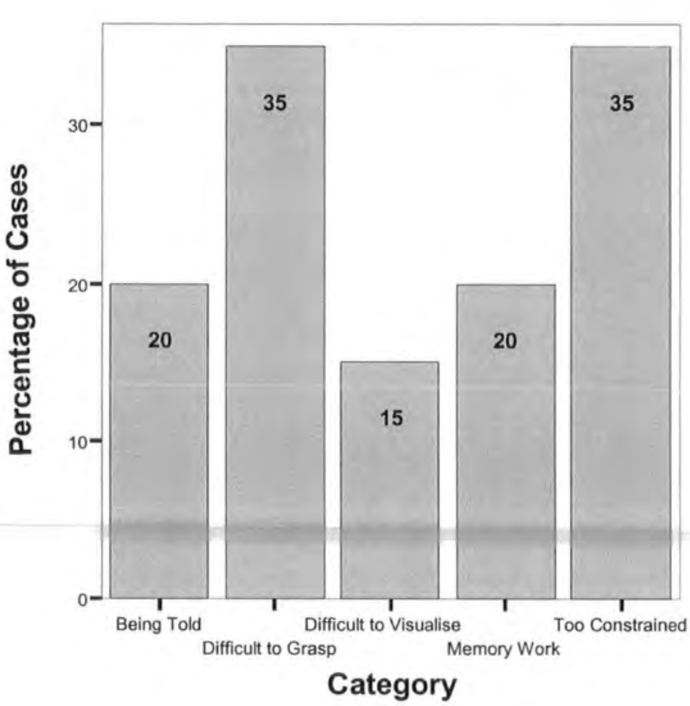
Bar Chart of Percentage of Cases - Group II, Question 34



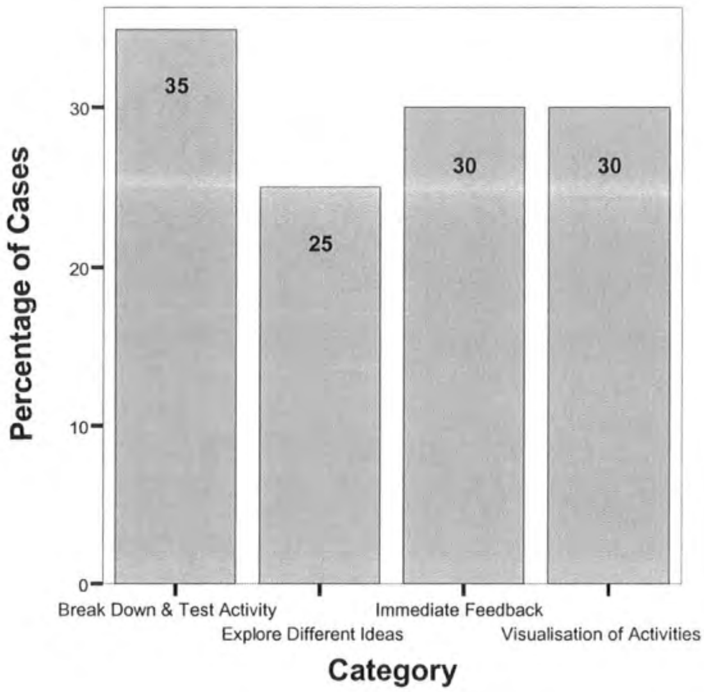
Bar Chart of Percentage of Cases - Group I, Question 35



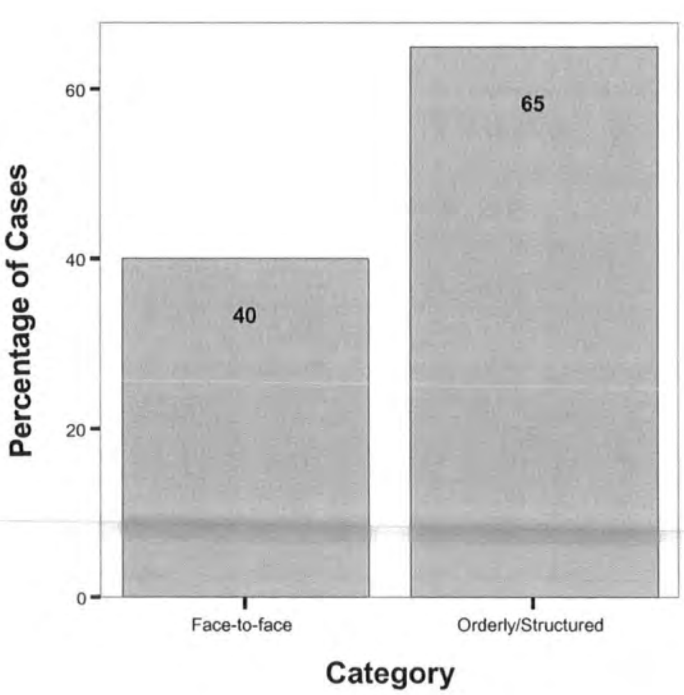
Bar Chart of Percentage of Cases - Group II, Question 35



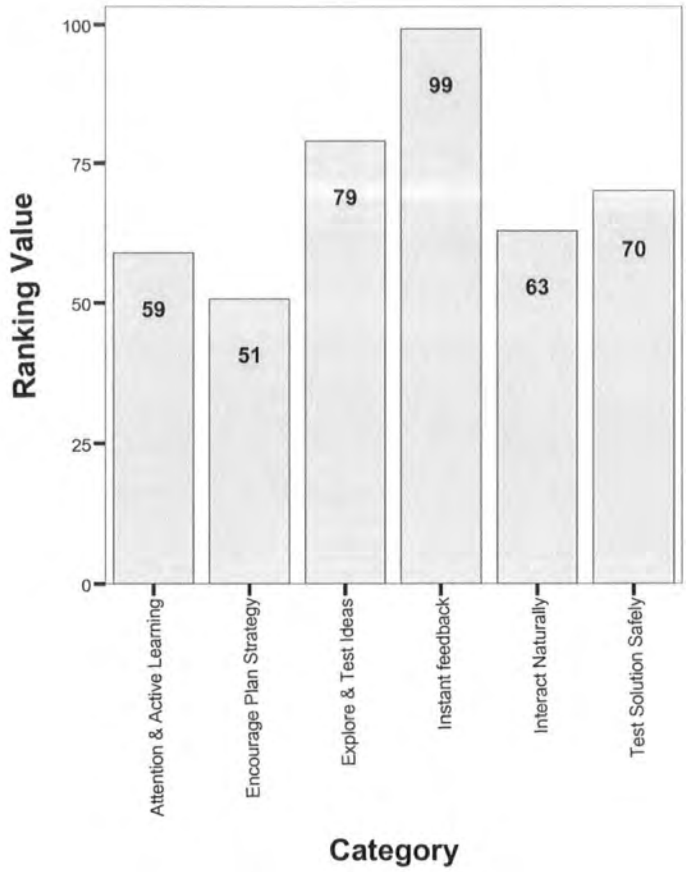
Bar Chart of Percentage of Cases - Group I, Question 36



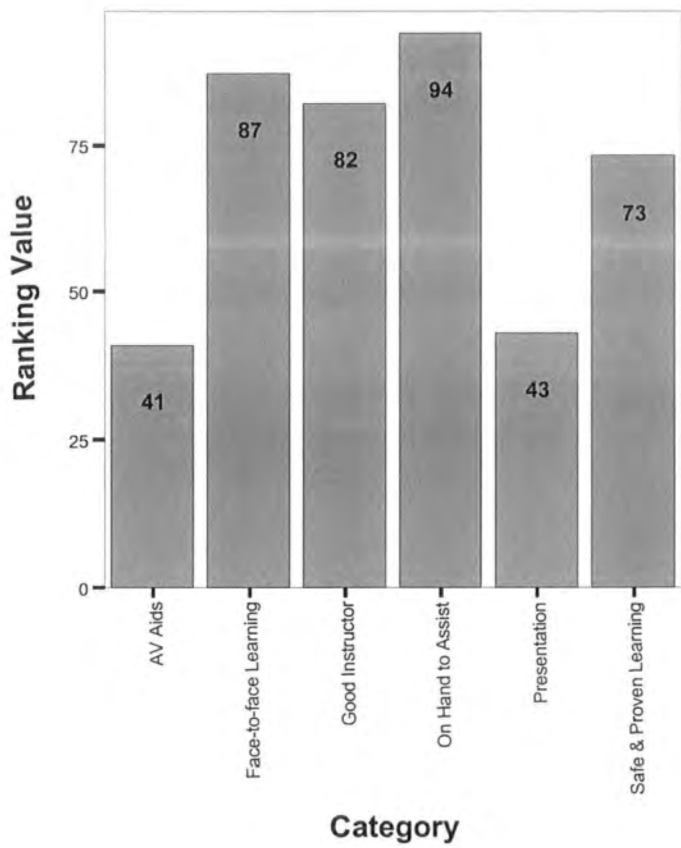
Bar Chart of Percentage of Cases - Group II, Question 36



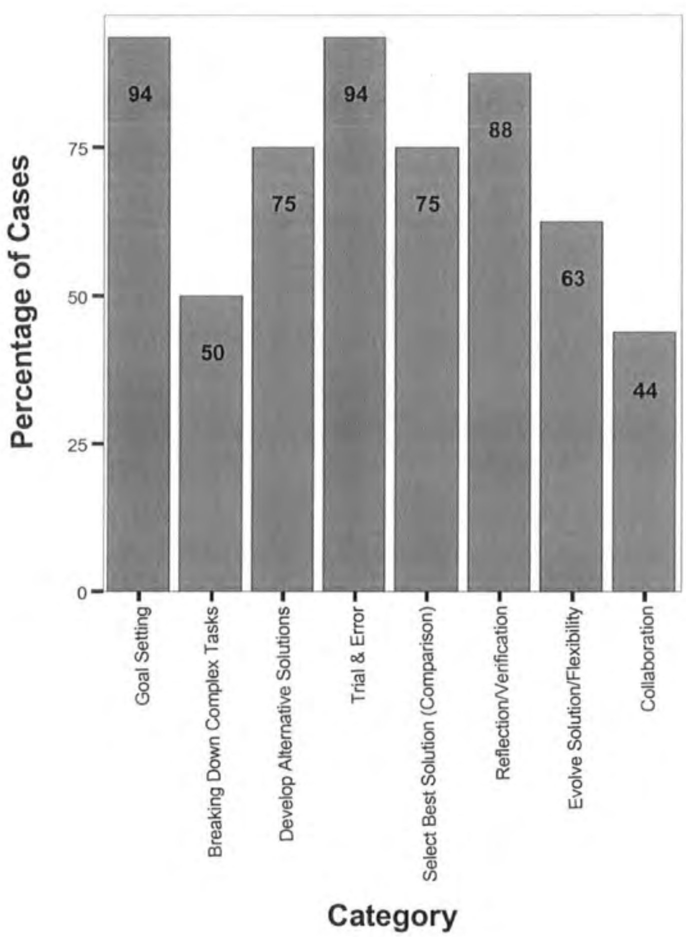
Student Ranking of Most Helpful Aspects of Learning in VR - Group I, Question 37



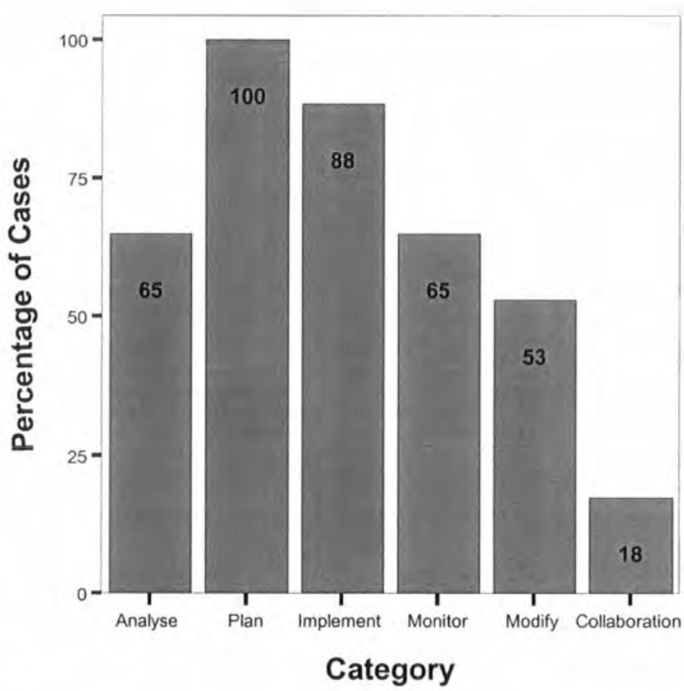
Student Ranking of Most Helpful Aspects of Learning in Traditional Settings - Group II, question 37



Concept Map Analysis - Group I, Question 38



Concept Map Analysis - Group II, Question 38



APPENDIX H

SAMPLE INTERVIEW TRANSCRIPTS

Student: __Student 3__

Group I Transcript

T: Interviewer
1s3: Interviewee

1	T	Why did you say that you learn better in virtual environments than through communications with your friends and instructors?
2	1s3	Through VR, I have a feel of the whole thing myself, rather than just what people tells me.
3	T	OK…
4	1s3	Some information being passed down to me may not be so true (accurate); (I'd) rather face (learn) the thing (topic/information) myself.
5	T	And….do you think you learn better using the system?
6	1s3	Because I will know how to solve when I faced the problem rather people teach me how to do it.
7	T	Were there any motivation factors involved? I mean…. do you feel you were interested?
8	1s3	(Nods)
9	T	OK, next question, in question 14, a question on whether you prefer to learn by directly interacting with the virtual environment, I noticed that you put "agree".
10	1s3	…I put disagree.
11	T	Uh disagree? Question 14? Oh..OK. You said that you prefer to get the information directly from the lesson… so in this case, by turning it around (by rotation, shows student he has selected the disagree item), it means that you prefer to learn by directly interacting with the VE.
12	ls3	Yes.
13	T	So is there a reason for not indicating "Strongly Agree"?
14	1s3	Because now we still cannot totally rely on VR, (it is) not so established yet. Down the road, the potential is there.
15	T	Do you think that the current examination system does not support this mode of learning because it is more tailored towards either more traditional means? What is your opinion on that?
16	1s3	Because some tests or exams cannot be catered through VR, …..
17	T	…..
18	1s3	Theory based (system) cannot be (using) VR so it is only (for) practical-based (subjects).
19	T	OK. In question 20, you indicated that you were able to solve problems with practically no help in the end. Why was this so?
20	1s3	Because as what I've said, once I see a problem, I will crack my brains (focus my attention) to solve it. So till the end, I will finally find a path with the help of real-life things (life-like simulations) because VR is somehow or other coming (close) to real-life.
21	T	So, in question 22, 23 and 32, you indicated that you were able to assimilate more information faster.
22	1s3	Yes
23	T	What made you say that you were able to learn more and also at a faster rate using the VE?

24	1s3	Some things (information) cannot be just (explained) by word-by-word explanation, it may not give a clear picture. If I face a real problem, I will understand it more, because the problem is generated by a real-life item, rather than just people telling you "You may forsee this problem" or "You may see this problem".
25	T	OK. In question 26 and 27, you indicated that you discussed solutions with your coursemates?
26	1s3	….. (nods)
27	T	And was able to arrive at solutions by working together? What did you actually do in your discussions?
28	1s3	Oh..(Solving) One problem with two brains, 2 person cracking (solving) one problem and the problem is a real-life problem (realistic simulation) and it is not a false (academic) problem. So we know what will be coming up next (the next step to take) and what caused the problem. And with more people, you'll have (generate) more ideas …..brain-storming.
29	T	OK. You indicated that the user-interface would be an obstacle to learning in question 19 and it was easy to arrive at a solution in question 21. Is there a contradiction?
30	1s3	For question 19, is based on (I am talking about) new users. For a new user, it is difficult for him to learn but once he pick up, it is easy for him to find a solution through the VR system.
31	T	….
32	1s3	Once he picks up the VR.
33	T	I see. So you're saying at the beginning, it is harder to learn.
34	1s3	New users may not be so good (used to the system) but once he picks up (gets accustomed to) the system, he will be able to solve the problems.
35	T	Right… so the next question, you mentioned in question 35 that VR/VE system…the graphics was not good. Can you elaborate on this?
36	1s3	Oh because I play (computer) games, it is always the graphics that will bring (make/motivate) you to carry on. Let's say you're given a 2D (2 dimensional, i.e. a picture) item to learn from there, you'll find it very boring. If you're given a good graphics software, from there you'll become more interested to see (explore) more and to learn more.
37	T	You're saying that the graphics need to be improved further. OK. Did you ever feel that the environment was very unstructured, for example that you could start from many points and then still get the (same) solution and does it allow the user to have a lot of freedom? Can you suggest whether there is some improvement that can be made?
38	1s3	Because it's all flexibility. In real-life, it is always flexibility (adaptability). So only the graphics needs to be improved. (Regarding) Interactivity depends on the user, how creative and how interactive (much he wants to learn) he wants to be. He may want to start from a certain point (direction), it is always on his free will (own decision) rather than being restricted (taught to do so). Being restricted is like learning from theory. Like being taught.
39	T	Right. You prefer to explore rather than being taught.
40	T	In question 37, ranking system on what aspects of VR is most important to you, you ranked planning as the second last item. What was the reason for this?
41	1s3	Because in VR, I can re-start (the experiment). Because you can test many

times without being hurt or kicked out (scolded). Planning comes then from experience. I will find the best solution.

42 T ......

43 1s3 But if I am given limited choice, I will plan it carefully but if I'm given unlimited choices, I would do a lot of (many) times to get the best solution.

44 T I see.....

45 T Refer to drawing, the concept map. I noticed that your system is one-way (single direction), could you elaborate on this because I would have thought that a concept map in a VR, it should be multiple directions rather than one direction because it is flexible and can arrive at many different solutions.

46 1s3 ....(pause) because at that point in time, only thinking of the start to the end, never thought of branching out.

47 T Right....you only focus on the problem

48 1s3 On a very general path because some components can be branched out to more minor things (components). Just used a block to represent (it).

49 T OK.. Thank you very much.

50 1s3 Welcome.

Student: Student 2

Group II Transcript

T: Interviewer
2s2: Interviewee

1	T	Let's make a start. Let's start with a generic question. You said that you prefer to learn by communicating with friends and instructors rather than by using a virtual environment. If you look at question 32 and 33, you say that you "Disagree" and that's the reason why I'm asking this question.
2	2s2	Oh..OK.
3	T	Could you tell me why you said you prefer to learn by communicating with our instructors and friends rather than with a VE?
4	2s2	Having (been) able to communicate with my instructors and my friends, I… for me, I'm not very comfortable dealing with computers, I like to have a person who can guide me through, .. with any medium, the medium is not important. Most important thing is, I need a person who can guide me through my problems.
5	T	Yes.
6	2s2	Be it mathematics, be it ... other subjects.
7	T	OK. So in that case, how were you able to motivate yourself through the process, let's say you're talking to an instructor or to your classmates?
8	2s2	Ah … the instructors and the classmates would often act as a muse, …
9	T	….
10		Because this very often triggers a spark ..
11	2s2	…..
12	T	The instructor, of course may not (give) direct help, but they are there as a sort of…. as an inspiration.
13	T	OK. OK. Great.
14	2s2	You understand?
15	T	Yes…yes.
16	2s2	Say if I'm talking to Celest, then she'll say … (indicates new idea)
17	T	Yes … its bouncing (off) ideas.
18	2s2	Yes.
19	T	Yes, understand. So in question 20, you indicated that you were not able to solve problems without help in the end. Why was this so?
20	2s2	Yes, this statement would best be applied to subjects like mathematics where you can refer to books. Examples in textbooks and reference books are ample and sufficient and they are good enough to help me through the course.
21	T	Oh. OK. You're saying that you prefer to learn from textbooks?
22	2s2	It is easier to learn from textbooks because you do not have to make appointment with instructor.
23	T	OK. Why was this so?
24	2s2	Why was this so? So if were to engage the instructor's help or to engage help of a friend, I would need to accommodate his or her time, and by knowing the textbook, I can study everything on my sweet time, provided the text book has sufficient examples, working examples for me to go through and to understand the concepts.

25	T	So your help is more like, reading books? How about with friends and so on.
26	2s2	… Reading books, this method is best applied to subjects that are theory-based ….
27	T	I see. How about let's say with a more practical subjects like CIM or factory automation?
28	2s2	Then I'd rather have help from my instructor or my friend.
29	T	….
30	2s2	There's active discussion. Active discussions can take place.
31	T	Ok. So you indicated in question 32 … that you'll be able to learn more from a VE.
32	2s2	Yes.
33	T	Why is that? It appears sort of like ….
34	2s2	Contradiction.
35	T	Contradiction.
36	2s2	Virtual Reality provides me with visuals, I can see what's going on because the instructor might say, elaborate in detail that the plant layout should be like this, or this …
37	T	…..
38	2s2	But it is best that I have a VR simulator that shows what it means.
39	T	….
40	2s2	All the visuals coming out.
41	T	I see.
42	2s2	These interactive visuals sort of strengthen the …understanding.
43	T	Understanding.
44	2s2	Understanding.
45	T	OK So let's take a look at 26 and 27. You indicated that you collaborated with your classmates. But in the concept map, the last question, there was very little evidence of this. Can you help me to sort of like, to understand this.
46	2s2	.... discussion in the course most probably happen in between tutorials and lectures ….
47	T	Oh OK. So this term here, "concept strengthen" ….
48	2s2	This "Concept strengthen" …by talking through the ideas….
49	T	So the concept strengthening, that's what you mean? You strengthen the concept by talking through the ideas …
50	2s2	Yes. Yes. So feedback and discussion most probably happen there.
51	T	OK. You indicated that the user interface would not be an obstacle to learning in question 19. Right? Would not be an obstacle.
52	2s2	Yes.
53	T	And then in question 33, that it is not difficult and painful to use. OK? However … you felt that it was difficult to arrive at a solution in question 21.
54	2s2	….
55	T	What was the reason for this? In question 21, you said it's difficult to arrive at a solution.
56	2s2	Question 21 and 33.
57	T	It's a contradiction.
58	2s2	Students will not face any problems using VR because in Mechantronics, we are exposed to a lot of (many) new software in the course, so students

will not have any problems.

59 T OK.

60 2s2 However, in coming to solutions like analytical problems, I strongly doubt that the VR simulator can … (pauses)

61 T … OK. So your view is that …..

62 2s2 That is not the problem but applying the system …

63 T To solve the problem?

64 2s2 To solve the problem (using VR) may be difficult.

65 T OK. You mentioned in question 35, that you took a long time to grasp and understand concepts in the traditional system. Question 35, right?

66 2s2 Yes.

67 T Can you further elaborate on this? Why did you take such a long time for a traditional system?

68 2s2 What the students go through in traditional system is that students will first be exposed to lectures, the lecturer will talk a lot about concepts, so the students need tutorials and labs to help them in understanding. So the period of time the student takes to (fully) understand a concept is not just conscious at the lectures but after the lab work where students go through the lectures, the tutorials and lab work.

69 T So you think that using the VR system is faster?

70 2s2 ….in the case of factory automation subjects like CIM, if the lecturer were to use VR in the lecture hall (theatre), I think students would be able grasp the concept in the lecture hall without going through the tutorials and the labwork.

71 T I see. I see. So you're saying that we should perhaps use some of this to demonstrate as we talk about the ideas.

72 2s2 This would shorten the learning curve.

73 T OK. Coming to the last question. You indicated elements of feedback, in words in the last question again, but it was not reflected in the diagram. Feedback means what we were talking about just now, talking, bouncing off ideas, so in your diagrams there is no feedback loop …. I see it is more sequential.

74 2s2 Oh. The feedback loop.

75 T You said you bounce ideas off people, right, so I expected to see some feedback loop in the diagram.

76 2s2 I don't understand. Why should I need a feedback loop.

77 T You understand the concept of feedback loop? In a traditional system, you modify your solutions according to what you received as feedback, it goes in a loop. Let's say in a lecture, the lecturer tells you something, if you're not sure, you ask questions, right?

78 2s2 More often than not, the feedback loop will happen in the tutorial. (gets idea finally).

79 T Let's say tutorial. So I didn't see it happening in the diagram. I mean the diagram is very sequential.

80 2s2 So in this case, (points to diagram) the students will go to the lecture, the lecturer will stress the points, the students get the idea …

81 T OK.

82 2s2 That means, OK I got it. Then he goes back. Most probably will forget. You need tutorial to strengthen the concept and …

83 T …….

84 2s2 Practical to finally grasp the concept.

85 T OK. So that's basically about it.

86 2s2 The feedback loop. Actually the feedback loop appears in my mind when I'm doing it.

87 T Ah. OK. OK. I was a bit curious because your system looks very sequential.

88 2s2 Lecturer is boring.

89 T (laughs). Just like to find out why. OK. Thank you.

Student: Student 3

Group II Transcript

T: Interviewer
2s3: Interviewee

1	T	Let's start with an easy question. Why did you say that you prefer to learn by using a VE rather than by communicating with friends and instructor?
2	2s3	Use VE can do at your own time.
3	T	OK.
4	2s3	You can repeat the process over and over again instead of one explanation from the instructor or even your friends.
5	T	OK. Second question. In question 20, you indicated you were able to solve problems without help in the end through traditional means, lecture, tutorial and lab. OK. Why is this so?
6	2s3	I agree with using VR to solve problems practically because I can see what I need to know so it cuts down a lot of time taken to understand the content from the text. But traditional methods also have their good points such as I would not missed out important points which I might have in VR.
7	T	OK. Understand. So let's look at the next question then. What made you indicate in question 32 that you were able to learn more from a VE?
8	2s3	(Pause)... Because certain subject that we study, it is better for us to study it visually than doing a lot of reading.
9	T	Ok.
10	2s3	Things (Subjects) like drawing .... Factory Automation ....
11	T	Factory Automation.
12	2s3	It is easier for us to see the real thing (simulation).
13	T	In question 26 and 27, right? 26 and 27 .... You indicated that you collaborated with your classmates, usually in a lecture or a tutorial, you talk to your classmates and then try to bounce (off) ideas that you were not clear, this is what I mean. In your concept map, the last question, you did not write any? Could you help me to understand how you collaborated with your classmates?
14	2s3	Usually in groups of 4 or 5, so there we will exchange what we know, if I don't know certain things, and another knows, I will approach him for help.
15	T	Peer teaching.
16	2s3	Yeah. Peer teaching.
17	T	OK. Let's look at another question. You indicated that the user interface is an obstacle to learning in question 19. ....
18	2s3	Agree.
19	T	However, you felt that it would not be difficult to arrive at a solution (using VR) in question 21. It is not difficult, because you "Disagree", right?
20	2s3	What I mean is getting to know the new interface. Because you are fresh to the software, you need to be familiar with the various icons, that the software provides. So this make take you some time to learn, but once you learn it, it would not be difficult for me to find a solution.

21 T Oh....OK. OK. You mention in question 35 that the traditional system of learning has a lot of memory work. That's one of the points you disliked about traditional learning. Can you tell me more? And how the system could be improved? To make learning easier and more interesting.

22 2s3 Certain concepts in the text, if we can see it visually, it would be easier for us to understand, rather than reading one huge chunk of text, where we need to digest the sentence and try to figure out the picture in our head (imagination).

23 T Right. Right. Thank you for your help.