Using visual representations to improve instructional materials for distance education computing students

Thesis

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Using visual representations to improve instructional materials for distance education computing students

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Abstract

Understanding how to develop instructional materials for distance education students is a challenging problem, but it is exacerbated when a domain is complex to teach, such as computer science. Visual representations have a history of use in computing as a means to alleviate the difficulties of learning abstract concepts. However, it is not clear whether improvements observed are as a result of improvements in the visual representations used in instructional materials or due to individual differences in students. This research examines the two themes of individual differences and visual representation in order to investigate how they collectively impact on improving instructional materials for distance education students studying computer science. It investigates the impact of different representations on learning while additionally investigating the relationship between individual differences and student learning.

The research in this thesis shows that visual representations are important in designing instructional materials. In particular, texts with visual representations have the power to cue students to perceive instructional materials as easier to process and more engaging. Investigation into the impact of concrete high-imagery versus abstract low-imagery visual representations illustrated that concrete visual representations incurred fewer cognitive overheads for computer science students and were able to ameliorate the challenges of learning computing.

The research in this thesis into individual differences demonstrated that Imagers did benefit more from studying instructional materials containing text with visual components. However the research indicates that appropriate selection of individual difference tests is dependent upon the application, i.e., whether the results are to be used to assess generalised tendencies or episodes in learning and whether the tests examine underlying approaches to cognition or practices in education.

An underlying question was whether students studying instructional materials containing low-imagery visual representations would cope as well as those studying high-imagery ones. Accomplished learners demonstrated that they could perform as well as with those receiving high-imagery visual representations. However, studying and recalling these materials did incur more cognitive processing.

This thesis argues that improving instructional materials by including appropriate visual representations is a useful basis for improving learning for distance education computer science students.

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Preface

This thesis has emerged as a result of my own experience as a part-time student and as a teacher of computer science. My part-time studies began about 25 years ago. I had always wanted to be a teacher, but a disillusioned careers teacher at secondary school advised me against this path. At this impressionable age I took his advice and left school; I didn't really want to do anything else so I thought I'd get a job instead. There were also other cultural influences in Northern Ireland at this time that steered me away from a university education. The expectation was that as a woman I would get married and stay at home with the children – so why go to the trouble of getting a university degree.

I was fortunate to secure a well paid job in the research laboratories of a tobacco company where I moved into the computing department. This was an interesting job and one were I gained my expertise in computing. However it soon became clear that I felt unfulfilled in this career and that I still wanted to teach. I then embarked on part-time study that has eventually lead to this thesis.

I began studying part-time in a college in Belfast and slowly began building up my education. After taking voluntary redundancy from my job I had the opportunity to do some part-time teaching in computing at college. This later led to a full-time teaching position in another college. It soon became clear that I needed to get some formal teaching qualifications and further enhance my computing credentials to secure a permanent job in a career I now so loved. So ambitiously I embarked on a part-time MSc and a higher education teaching diploma in the University of Ulster as well as being a full-time teacher and a mum.

This experience gave me a real taste of the pressures that part-time students face when they have full-time jobs and families. My educational experience was that traditional lectures were not always satisfactory ways for part-time students to learn. I was an early adopter of technology and used it in my teaching. I could see its potential for helping part-time university students. I pursued this theme in my MSc to investigate the use and value of technology for teaching computing students that were studying off campus.

As a result of this research in my MSc, the University of Ulster asked me to teach a module in technology in education on the certificate part of the MSc I had just finished as well as developing materials suitable for such students studying at a distance. My interest in technology in distance education led me to securing a job in the computing department of the Open University, where I was able to pursue these themes further.

I embarked upon a PhD where the goal was to examine how I could improve learning for distance computing students. I registered for a PhD in the computing department and began pursuing my research. The process of setting up and carrying out the research was conducted in the computing department under a computing supervisor. During this time it began apparent that the issues I was interested in were associated with educational technology and not solely with computer science.

I moved jobs and secured a lecturing position in the Institute of Educational Technology (IET). I then acquired a second supervisor in IET, Professor John Richardson. This was an excellent move and really enabled me to strengthen the research in the area of student learning in which I was most interested. Later Professor Richardson secured a chair in IET and I was to be able to move my PhD to IET. I was fortunate enough to have Professor Richardson appointed as my first supervisor and Ann Jones as my second supervisor.

These events have caused me to move disciplines in both my career and my research. As the process of collecting the data was conducted before moving to IET it has had the effect of producing a rather less conventional PhD in educational technology that might normally be expected. As my PhD research began in computing, the culture determined how the research was conducted. Moving the PhD to IET has enabled me to have access to ideas and literature in educational technology that were not prevalent in computing. Access to these resources has reshaped my thinking and the rationalisation of the research in this thesis.

Although I have used research methods from other disciplines, particularly in psychology, I have no formal training in psychology or in research methods. This is unfortunate, as although I have spent considerable time getting to grips with research methods, a good grounding in psychological and educational research methods would have given me more confidence in reporting my research.

My personal journey of discovery in this thesis has involved moving disciplines and having greater access to the culture and issues in educational technology that now so dearly interest me. I now have a greater understand of the depth and breadth of the questions, with a few answers that I argue in this thesis. However, my realisation at the end of this journey is that in the scheme of things, I still know so little and there is still so much to know.

This research has given me the opportunity to understand and explore some of the issues in educational technology. It has given me a good grounding in the literature in this domain, and has equipped me with a set of tools that I hope will serve me well in the research I plan to do in the forthcoming years. The excellent training that I have received under the auspices of Professor Richardson and Dr Jones has developed my skills and inspired my research interests. My goal for the future is to take this excellent apprenticeship forward to carry out further research into ways of improving learning for part-time distance education students.

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And last but by no means least; the final and most important acknowledgement goes to my loving husband Blaine who helped with domesticity, childcare, IT support, thesis reading and all the other things that go with partnering a part-time PhD student. But most of all he gave his love and helped me to achieve a goal that meant so much.

Chapter 1 Introduction

1.1 Background to thesis

Studying abstract topics at a distance presents students with challenges. One example of an abstract subject is computer science, which is affected by representation where conceptual difficulties and the style of representation interplay. The nature of this complexity hinges on computing artefacts, such as applications software, operating systems and microprocessing systems, which are changeable, invisible, and react with other systems where consequences can be unpredictable. These artefacts are abstract and difficult to observe, encompass many levels of abstraction, and require reasoning about the behaviour of processes through time (Daniels, Petre, & Berglund, 1998; Naps & Chan, 1999). Students are required to infer the functionality of processes by observing interactions with the real world (Du Boulay, O'Shea, & Monk, 1981; Jones, 1993). Thus teaching in this domain is complicated and representing computing concepts accessibly is challenging.

Distance education adds to this complexity. Whilst it offers education to those constrained by geographical, temporal, financial and personal circumstances, such constraints also add difficulties, since students are remote and isolated. These constraints make considerable demands on distance education instructional materials: They need to replace an interactive teacher who can adapt pace, style of instruction, content, and remediation when necessary (Dekkers & Kemp, 1995). Similarly distance education has to mimic communication interactions present in face-to-face teaching and learning with teachers and peers. The demands and expectations from distance education instructional materials are great and distance educators constantly need to refine and improve practices to retain students in this isolated form of learning.

The challenges of teaching computer science at a distance are further complicated in the teaching of certain problem areas. Concurrency is a topic that presents learning challenges for computing students (Adams, Nevison, & Schaller, 2000; Ben-Ari & Kolikant, 1999; Choi & Lewis, 2000; Exton & Kolling, 2000; Feldman, 1992; Hailperin, Arnow, Bishop, Lund, & Stein, 2000; Hendrix, Cross, Maghsoodloo, & McKinney, 2000; Jackson, 1991; Naps & Chan, 1999; Yeager, 1991). Concurrency deals with how computers can *apparently* run two or more processes in parallel. Students have difficulty understanding how this operates inside the computer and how they develop processes to run in parallel. They find it difficult to extrapolate from an inherently concurrent world to the realms of computing, where events, such as booking theatre tickets or flight reservations by telephone, are common occurrences.

In computer science, visual representations are frequently used to relieve abstraction, both in practice and in education. However, many of the visual representations used in textbooks discussing concurrency rarely make concrete connections for novice students and similar concerns could be levied at self-study texts (McAndrew, Carswell, & Rae, 2001). Representations can frustrate learners when the meaning is complicated by the choice of representation, only adding to the learning complexity. It is not clear whether students would prefer visual representations in their instructional materials, or whether visual representations improve learning for computer science students.

These problems present two issues of interest: one considers how best to represent materials, the other considers some of the factors that may contribute to differences in learning. Within the Open University (Lawless & Freake, 2001; Rowntree, 1986, 1997) and in the wider field (Dekkers & Kemp, 1995; Hartley, 1994, 1995; Lowe, 1995) research into instructional materials has offered guidance on development. However, there has been little empirical work investigating student choices in representations and the effect of those choices on learning. Often the design of instructional materials is based on the developer's own beliefs of 'good' representation with little consideration of how a learner might use the materials (Dekkers & Kemp, 1995).

Investigating student representational preferences and their effects may offer knowledge into how instructional materials could be improved. However, there is some debate about the effectiveness of using additional representations such as diagrams in improving student learning or what advantages they afford learners (Ainsworth, Bibby, & Wood, 1998; Bertin, 1981; de Jong et al., 1998; de Jong & Ferguson-Hessler, 1991; Mayer & Anderson, 1991, 1992; Mayer, 1989, 1997, 2000; Mayer & Gallini, 1990; Mayer & Sims, 1994; Paivio, 1978; Petre & Green, 1993; Scanlon, 1998; Scanlon & O'Shea, 1988).

Individual differences in learning, such as cognitive styles and learning styles, have featured in research into instructional improvements. The major assumptions of these approaches are:

- that it is possible and desirable to adapt the nature of the instruction to accommodate differences in style, ability or preferences to improve learning outcomes (Jonassen & Grabowski, 1993)
- that different learning outcomes can be attributed to particular learning traits (Pask, 1976).

However, there is some debate as to interpretation and usefulness of individual difference inventories. The area would benefit from further investigation into learning differences and outcomes associated with different representations (Hashway & Duke, 1992; Messick, 1984; Miller, 1991; Pask & Scott, 1973; Richardson, 1998b; Riding & Cheema, 1991; Squires, 1981).

Investigating both representational issues and individual differences offers parallel but complementary knowledge into improving instructional materials so as to ameliorate the difficulties of learning computing at a distance. Using visual representations in instructional materials may have attendant cognitive issues. For example, if individuals have particular traits that predispose them to learn in a particular manner, such as visualisers preferring visual representations, then representations tuned to learners preferences may offer cognitive economies, and vice versa.

Investigating individual differences in learning would therefore have three roles if examined in parallel with representation:

1. To investigate the contribution of individual difference measures into improving instructional materials for learning.
2. To assess whether any particular group of individuals, categorised by an individual difference trait, had any learning advantages over their counterparts.
3. To assess whether tools, such as individual difference tests, provided appropriate information in practice-oriented research: the examination of performance and process in task- and context-specific episodes in learning.

Representation and individual differences are parallel but linked themes in exploring the most useful approach for improving instructional materials. There has been a recent resurgence of interest in the use of individual differences in human learning research, particularly when developing electronic materials for the web. In this context, interest centres on reusing learning objects for individualised instruction (Hannafin, Hill, & McCarthy, 2000; Martinez, 2000; Merrill, 2000). Research in this thesis may have some impact on the usefulness of individual differences when developing individualised instruction.

A further underlying question in this research is whether students use strategies to compensate for less favourable representations of instruction materials. For example, if two groups of students were provided with different instructional materials, where one set of materials was deemed to be of a more abstract representation and consequently more difficult to engage with than the other, would there be any difference in their learning outcomes and learning processes? This may be important in order that the value of comparing learning outcomes in test situations may be scrutinised. If students do compensate for materials, then comparisons between learners may need to be examined by other more probing means than post-tests.

A final thread to this research is the current growth of visual representations in wider contexts. Understanding some of the issues of representation may feed into future developments of electronic instructional materials. For example new devices, such as hand-held computers and interactive digital TV, increase the challenges of representing information for a range of platforms because of different or limited screen display areas. How to represent instructional materials for these platforms still needs to be explored. While such research is beyond the bounds of this thesis, the research presented here is likely to have some impact on the design of instructional materials for these devices.

In short, investigating how information is represented and its effect on cognitive load can provide valuable information in the design of information (Van Hout-Wolters & Schnotz, 1992). In particular, computer science presents learners with challenges due to inherent domain-specific complexities. Representation of instruction and individual learning differences will be considered within this domain to explore which of these factors affect learning when representation is manipulated so as to improve instructional materials for teaching a complex topic at a distance.

1.2 Aims of the thesis

This thesis explores two parallel but related themes of representation and individual differences in learning. It examines which factors affect learning outcomes when representations are manipulated. This thesis takes a 'back-to-basics' approach and investigates paper-based instructional materials to determine the underpinning factors capable of improving instructional materials for teaching abstract topics at a distance without the complications of media effects.

The parallel themes of *representation* and *individual differences* are examined to assess whether improvements in instructional materials can be attributed to the manipulation of representation or to inherent individual traits of students. The individual differences approach seeks to understand some of the issues pertaining to student learning and explores whether these affect learning. The representation theme examines students' preferences for representation and how the manipulation of these choices affects learning. The learning improvements are explored through learning outcomes and learning processes.

1.3 Research brief

There are two studies in this thesis. The first study examines preferences for representation in learning in computer science. The representation of materials was manipulated and individual differences were measured. Students and academics were exposed to four topics, each one presented using one of four different types of representation to assess the impact of different representations. Reports were elicited from students and academics on their perspectives of representations, which were compared and contrasted. Students were tested for incidental learning and their answers were scrutinised for links with the use of visual representations. Knowledge was also elicited from academics on representational design issues about best practice. More specifically the following points were addressed:-

- What are students' preferences and perspectives on representation?
- What are academics' preferences and perspectives on representation?
- How do academics' and students' preferences and perspectives differ?
- What are the design issues identified by academics in representation?
- Is any incidental learning observed as a result of students' being exposed to the knowledge elicitation activity and is it linked to any particular representation?
- What is the value of individual difference measures in predicting preference for representation in academics and students?

The second study manipulated visual representations and monitored individual differences, where concurrency was the exemplar of a conceptually difficult area in computer science. Two groups of students were administered high and low-imagery visual representations, respectively, to compare learning outcomes and processes.

Students' scores on post-tests were examined to establish whether there was a link between representation type and score. Students' introspective reports were also examined to establish levels of cognitive processing used in studying and recalling information. Individual difference measures were used to establish their value in predicting performance.

Additionally the study considered their value as research tools in examining specific episodes in learning. More specifically the following points were addressed:-

- What is the relationship between post-test scores and the two different treatments of visual representations in instructional materials?
- What are the effects on cognitive processing of high-imagery and low-imagery visual representations in instructional materials?
- What is the value of cognitive measures in predicting performance in students exposed to high-imagery and low-imagery visual representations in instructional materials?

This thesis focuses on understanding the value of visual representations for students studying conceptually challenging areas at a distance. It also examines other factors that can affect learning performance and outcomes in this educational context and domain.

1.4 Overview of the thesis

Chapter 2 describes the problems inherent within computer science and how they impact on learning for computing students. This chapter reviews distance education in the context of this thesis. The chapter outlines why an investigation into representation and individual differences in human learning is warranted.

Chapter 3 provides a review of the individual differences literature in human learning. It highlights the relationship between individual differences and learning and how researchers have used this work to predict performance and preference for instruction in educational contexts. The review also highlights stability, reliability, consistency and specificity issues. The review is structured using Curry's (1983) model to add coherence to the domain.

Chapter 4 provides a review of the representation literature. It illustrates some of the cognitive and semantic issues in representation. The properties of representation are explored to explain the variance in results. Dual processing is used as the theoretical basis to explain variations in outcomes.

Chapter 5 elaborates the aims of the thesis and describes the aims and methods of Study 1. The thesis aim is to explore the use of visual representation to ameliorate the difficulties of learning computing at a distance. The aims of Study 1 are to examine preferences for representations and factors affecting those choices. The data requirements for this study are examined and the literature is reviewed for appropriate methods to support the required data collection. The methods used in this study are card sorting, laddering, Group Embedded Figures Test, Cognitive Styles Analysis test, the Learning Style Questionnaire, background questionnaire, incidental learning post-test, and case analysis interview.

Chapter 6 describes Study 1 where students and academics provided information about preferences for representation through the card sort and laddering activity. Preferences were compared between groups. Students were found to significantly prefer instructional materials containing visual representations.

Chapter 7 builds on Study 1 and further reviews the literature on visual representations examining their history, their use in learning and their use in computing. This leads to a definition of the research aims in Study 2 and an analysis of the data requirements. Study 2 investigates the effect of high versus low-imagery visual representations on learning. Post-tests, similar to those of Mayer (1989) are used, coupled with introspective reporting of learning processes. The Group Embedded Figures Test, Cognitive Styles Analysis test, the Learning Style Questionnaire and background questionnaire are used as in Study 1.

Chapter 8 describes Study 2, which compares the effect on learning outcomes and processes, of studying either high or low-imagery visual representations. The results indicate that high-imagery visual representations are valuable for novice computer scientists. The study also leads to the conclusion that individual difference tools may have limited value in practice-oriented research examining task- and context-specific episodes of learning. This leads to the development of a model that illustrates factors affecting performance in these circumstances.

Chapter 9 describes the main achievements of the thesis and their implications for educational technology, computer science and student learning research. Visual representations with text are identified as being valuable for students where they are cued to perceiving them as easier and more engaging than all text representations. High-imagery visual representations were shown to be valuable in learning difficult concepts in computing. The individual difference tests were shown to have limited value in practice-oriented research examining episodes in learning. The research in this thesis leads to a model illustrating factors affecting performance in examining specific learning episodes.

Chapter 2 The Problem Domain: Teaching Abstract Topics at a Distance — Computer Science as an Example

2.1 Introduction

This chapter examines the issues involved in teaching abstract topics at a distance using computer science as an example. It reviews the complexity of understanding computing artefacts that are abstract dynamic models changing with time. The chapter identifies concurrency as a conceptually difficult area of computer science for students and explains why this presents learning problems. It examines how the challenges of teaching a conceptually difficult area are amplified by distance education. It reviews why remote learners, who study part-time off-campus with limited time and resources, require clearly represented self-study texts. Information representation and individual differences in learning are two parallel but related themes identified as informative for the development of improved instructional materials to ameliorate the difficulties of learning computer science at a distance.

2.2 The Open University Distance Education Student

Studying at a distance offers flexibility to students but also presents learning challenges depending upon the interpretation of the distance education programme. Although the term 'distance education' is used universally, its meaning is variable and there are many models of distance education depending upon country, culture, scale, and operation (Jones, 1996; Keegan, 1996; Thomas, Carswell, Price, & Petre, 1998). Finding a universal definition for distance education is difficult due to the blurring of boundaries between traditional and distance education, and differences in cultural perceptions of distance education (Barker, Frisbie, & Patrick, 1989; Carswell, 1998b).

Some models of distance education are variations on campus-based lectures using technologies such as satellite broadcasting and video conferencing (Barker et al., 1989; Minoli, 1996; Owen, 1996). Other systems allow external part-time study of traditional university courses, and further models provide traditional lecture notes as self-study texts (Thomas et al., 1998).

Many of these models are limited by temporal and geographical restrictions requiring students to 'meet' at the same time, or at the same place, and possibly both. An example of this is where lectures are broadcast by satellite to students' homes, or to a campus remote from the lecturer. All students have to 'attend' a lecture at the same time.

In contrast, the Open University (OU) model of distance education is not restricted by geographical or temporal constraints. Students have the flexibility to study at a time and place of their choosing using self-study texts (although the OU too has experimented with tutorials via satellite: Thompson & Jelfs, 1997). Garrison (1989) refers to this model as '*education at a distance*' where the actions include all of the educational activities between a student and a teacher who are physically remote from one another (Moore, 1973). Keegan (1996) agrees and argues that the magnitude of the geographical separation is not the defining factor but that the distance between the teaching and the learning acts is.

For example, students and teachers may be physically remote but have a lecture or tutorial by satellite. In this case the teaching and learning activities are not separated by time, although the students and teachers may have huge geographically separation. However students who receive education via self-study texts have both teaching and learning activities separated by time and distance. The learning and teaching materials are prepared well in advance of the student receiving them and the learning takes place separate from the teaching activity, even though they may only be a few miles apart geographically.

Another model of distance education uses satellite lectures. The teacher has flexibility to alter the content and style of teaching, should the need arise, and the ability to respond to particular difficulties experienced by the learner. In contrast, the Open University model has little opportunity to adjust the instruction during the course where print is the main medium.

Institutions that offer both campus-based education and distance education can be considered as *dual-mode*; while those, such as the OU, that offer only distance education can be considered as *single-mode* (see Richardson, 2000, for further discussion). The difference being that institutions such as the OU have courses specifically designed for remote students whereas the dual-mode institutions were primarily designed for campus-based students (Richardson, 2000).

In this thesis distance education will be understood to mean single-mode distance education which is not restricted by time or place and where the learning and teaching acts are separated by time and distance (Carswell, 1998b). In this model of distance education there is a trade-off between flexibility for the learner, in terms of time and place, and lack of flexibility for the institution where all the teaching materials are prepared in advance and cannot be readily changed during the course. The OU model contains resources specially designed for the distance student and has a good record of providing students with a support network for learning (Thomas et al., 1998). However, students are remote from their instructors, fellow students and campus resources, and are essentially 'lone learners' (Morgan, 1997). The bulk of instruction is provided through self-study texts, but these have the disadvantage of being solitary. They lack the capacity for immediate remedial human intervention since interactions are asynchronous (Abrami & Bures, 1996; Barker et al., 1989; Carswell, Thomas, Petre, Price, & Richards, 1999; Morgan, 1997).

At present, distance education and technology, particularly the web, seem inextricably linked (Abrami & Bures, 1996; Barker et al., 1989; Bischoff, Bisconer, Kooker, & Woods, 1996; Carswell, 1998b; Ellis, Torokfalvy, & Carswell, 1998; Moore, 1996; Moskal, Martin, & Foshee, 1997; Tolley, 2000). However, technology alone cannot resolve the long-standing challenges of teaching at a distance, (Carswell, 1998a; Petre, Carswell, Price, & Thomas, 1998). Teachers need to understand how to represent information and its impact on learning so as to provide accessible, engaging materials.

The fundamental issue of how to design effective materials seems to be overlooked (Bates, 1991; Kling, 1983; Petre, Carswell et al., 1998). The effect of different representations on student learning through self-study texts is obscure, as there is scant empirical research on their use. Since self-study texts are the mainstay of Open University distance education programmes, the manner of representation is important to help develop engaging materials. Understanding how representation affects student learning will be increasingly important with the fast moving trend towards electronic instructional materials for the web and for other platforms such as hand-held-devices (Waycott & Kukulska-Hulme, 2001) and interactive digital television.

2.3 The Difficulties of Teaching Computer Science

Computer science is an interesting area to investigate. It presents learners with abstract concepts that they need to understand, while teachers need to be able to represent these concepts and behaviours as accessibly as possible. It has similar challenges to areas in physics and engineering where students grapple with understanding the behaviours of invisible abstract artefacts that interact with objects in the real world.

For example, a computer program is static and lifeless until the point of execution where it becomes a dynamic object and its functionality is realised. The processing takes place inside a computer preventing students from observing what they have created. Instead students need to reason about a process in isolation of any direct observation. Changes to the program are only possible when the actual functionality of the program is known. In order to develop a successful program the student is required to understand how the program will operate — in advance of runtime. The modelling of computer instructions is an individual cognitive process, not easily articulated or tested. The point of execution becomes the real test of conceptual competence and uncovering failing components is difficult.

Computer science, like other domains, has many levels of abstraction. These abstractions can pose conceptual difficulties of their own, making knowledge transfer between contexts more difficult (Oberlander, Monaghan, Cox, Stenning, & R., 1999). In computing, instructions manipulate symbols as opposed to familiar real world objects (Lesgold, 1998).

Novices find computing difficult because their mental models are inadequate to cope with the range and levels of abstractions required to understand the concepts (Greening, 1999) and because the functional representation is not made explicit (Jones, 1993). Kahney and Eisenstadt (1982) and Kahney (1982) showed that novices' mental models of program processes were reliably different from those of experts, and that novices had gaps in specific programming fragments that required 'filling in'. Many iterations and interactions are required before novices can construct their own personal models of concepts and processes (Cox, 1999). Previous research has suggested that visual representations can facilitate the development of students' own mental models, enabling them to visualise abstract concepts (Du Boulay et al., 1981; Jones, 1993). The aim of this thesis is to examine this in more detail.

Computer science also has attendant pressures, such as market forces, which impact on what is taught and how. There is a continued tension between rigour aimed at producing reliable quality software (Fung, O'Shea, Goldson, Reeves, & Bornat, 1993) and rapid production to meet market pressures. Rigour in software production has arguably been eroded by the changes witnessed in computing over the past 40 years. For example, technological infancy, (such as, machine code programming, punch cards, and overnight batch processing on central computers), required students to rigorously understand the programs they were creating, as running programs was time-consuming and costly. Today's students have ready access to personal computers, so adopting trail and error approaches, as opposed to reasoning logically through the steps in a program, is easy to orchestrate (Zweben, Stringfellow, & Barton, 1989).

Computing students are on the receiving end of continual change in the curriculum and this makes the teaching and learning of the topic difficult. These factors invariably affect the teaching of the subject and present learners with difficulties in keeping pace with a moving curriculum that has different teaching paradigms. For example, teaching programming has moved from a procedural paradigm to an object-oriented one and computer science teachers are still debating the best way to teach this and the most appropriate programming language to use. Thus educators grapple with what to teach and how to teach it (Daniels et al., 1998; Denning, 1999).

These factors make computer science an interesting example of the challenges of teaching abstract concepts at a distance. It has a short history as a discipline and lacks well-rehearsed teaching conventions. Understanding how visual representations can contribute to students' comprehension of this domain will be useful in improving educational materials for distance students.

2.4 The Difficulties of Concurrency

It is generally accepted that concurrency presents learning difficulties for computing students as they struggle to understand how processes run in parallel inside a computer (Exton & Kolling, 2000; McAndrew et al., 2001). It is an important theme for students as it permeates many areas of computing such as architecture, operating systems, distributed systems, and parallel algorithms (Jackson, 1991; Yeager, 1991). It is frequently left until later in the curriculum, which can be problematic as students introduced to procedural programming first find it difficult to make the mental switch to concurrency (Yeager, 1991). Concurrency *per se* is not hard as students naturally exist in a world that is concurrent in nature, but it does require a different mode of thinking (Ben-Ari & Kolikant, 1999; Hailperin et al., 2000).

A real world example of concurrency is eavesdropping on one conversation while being engaged in another conversation. Another example is an airline seat reservation system where several travel agents might be accessing the same records concurrently with apparently simultaneous actions taking place. However, mapping between abstract concepts and their more concrete representations is difficult, but it is typically how experts function (Jones, 1993; Kahney, 1986). Novices lack understanding of the theoretical basis for concurrency. The abstract nature of processes operating concurrently inside a computer has deficient mappings to the world students understand.

Ben-Ari and Kolikant (1999) conducted a study into the problems of learning concurrency for 17-18 year olds and identified the following conceptual problems when studying a model of concurrent processes.

- Students lack understanding of the underlying concurrent model
- Students have misconceptions about the concurrent model
- Students have difficulty in applying the concurrent model

The lack of *understanding of the model* means students do not comprehend the types of operations specified by the model and what types of operation it defines. Misconceptions of the model lead to inappropriate assumptions about its behaviour that are inconsistent with the specification of the model. Difficulties with the application of the model give rise to inappropriate assumptions about solutions within the model. For example, a student may envisage a sequential solution to a parallel problem (Ben-Ari & Kolikant, 1999). Yet some students manage to cope with these issues. Understanding some of the cognitive issues involved could provide information about student learning in this conceptually difficult area.

Teaching concurrency at university level has not had this same kind of cognitive analysis. Instead problems are characterised by topic areas as opposed to analysis of underlying reasons for misunderstandings (Choi & Lewis, 2000; Hailperin et al., 2000) These topics are identified as:

- Concurrency execution and its necessity
- Data races and synchronisation
- Deadlock including lock passing and deadlock detection

This collection of topics is subject-specific and it is reasonable to assume that the problems identified by Ben-Ari & Kolikant lie at the root of the problem.

Teachers have provided various methods for concretising concepts to aid understanding (Ben-Ari & Kolikant, 1999). In some instances these are applications of theory where students are provided with an opportunity to experiment in a hands-on situation (Adams et al., 2000; Oh & Mosse, 1999; Yeager, 1991). In others they take the form of visual representations (Hendrix et al., 2000) making explicit either a teacher's or another person's mental model of the underlying theory (Dicheva & Close, 1996). In software development, visualisations are used to relieve the burden of abstraction and help with debugging programs (Baecker, 1998). The use of different representations plays a part in relieving some of the complexity of teaching this subject.

When teaching computing at a distance, relieving complexity is even more important because students cannot ask a teacher for further explanation. However, there are additional complicating factors. First there is the nature of the domain, which is abstract, complex and continually changing. Secondly, the teaching of the domain is complicated by continually changing curricula, competing teaching objectives reflected from industry, and the encouragement of fluidity in practice. Finally, there is the nature of distance education that constrains how the education is delivered, which impacts on how instructional materials are developed. External pressures on computing cannot be addressed; however, improving instructional materials may tackle some of the challenges of studying at a distance.

At a more pragmatic level, to consider how widespread the problems of concurrency were for students, internal and external reports on students' problems with concurrency were investigated. First, internal course survey reports were examined from an Open

University Operating Systems course that contained a component on concurrency. These reports were evaluations of the course components from the students' perspective and reported how difficult students found particular aspects of the course. These indicated that concurrency regularly caused learning difficulties for students. Second, external professional bulletins reporting problems other computer science teachers were encountering were examined. These were published papers in ACM's Special Interest Group for Computer Science Education (SIGCSE) bulletins. The bulletins reviewed were from September 1991 to June 1999 and illustrated that concurrency was a commonly reported problem area in computer science teaching. As concurrency appears to be a good example of a conceptually challenging area, evident in internal and external sources, it will be used in Study 1 and Study 2 as an example of a conceptually challenging topic in computing.

2.5 Addressing the problem

There are two aspects of interest in addressing the problem of improving materials for students studying at a distance. One aspect is the individual differences in student learning and the factors that affect them. The other aspect is understanding how to represent instructional materials so as to improve learning for students. Computer science educators are interested in understanding student learning to grasp some of the cognitive demands facing students and their different approaches to study (Kurland, Clement, Mawby, & Pea, 1984). This requires an understanding of individual differences in learning, how these traits can be characterised, and how their individual differences may affect learning outcomes. Some of the issues that can interplay when learning computing are:-

- The ability of students to construct artefacts for themselves

- The ability of students to invoke mental images of processes in action and thus develop individual mental models of their enactment
- Individual difference traits in students that may conflict with the way in which programming, and computing in general, is taught.

Structuring skills form an important part of programming and students need to be able to create their own structures when designing and creating computing artefacts. This is an important skill as programs need to be structured coherently to ease design and maintenance. Similarly, visualisations play a role in computing (Baecker, 1998; Hendrix et al., 2000). Students need to be able to either imagine what is happening with invisible processes or interpret supplied visualisations in order to reason about process behaviour (Foley, 1998). Additionally individual style may be a factor in how students learn computing and particular instructional designs may interplay with how students learn. Research into individual differences could offer some explanation for accommodating these issues in learning computer science (Stenning, Cox, & Oberlander, 1995).

To investigate what factors influence improvements in instructional materials, empirical evidence is required of both the effects of manipulating representational properties and the influences of individual learning traits. This needs to be obtained from a student perspective to consider what their representational preferences are and how they might impact on learning cognitively challenging concepts. In addition, research into how teachers develop instructional materials could provide guidance on how to use representations effectively for learning in this domain and mode of learning.

The themes of how to represent information for learners to improve learning and the influence of individual differences when studying these representations are parallel but linked. It may be that an improvement in learning could be attributed to an improvement in the instructional materials, the influence of a particular learning trait, or both. They need to be investigated together to establish what factors contribute to improving instructional materials for teaching conceptually difficult topics. Thus investigations into improving instructional materials can be studied from these two complementary perspectives. That is,

- To what extent do individual differences influence learning?
- To what extent do different representational properties in instructional materials influence learning?

This dual approach to investigating learning has a long history in the study of cognition, particularly individual differences in visual-verbal traits and imagery (Barratt, 1953; Bartlett, 1932; Cohen & Saslona, 1990; Hiscock, 1978; Paivio, 1971; Richardson, 1977a) (for further details see Richardson, 1999b). The two themes of individual differences and domains that present learners with challenges have similarly been investigating in computing (Campagnoni & Ehrlich, 1989; Cox, 1999; Mayer & Anderson, 1991, 1992; Mayer, 1989, 1997, 2000; Mayer & Gallini, 1990; Mayer & Sims, 1994; Mousavi, Low, & Sweller, 1995; Stenning et al., 1995; Stenning & Oberlander, 1995).

The next two chapters review the literature on individual differences in learning literature and the representation of instructional materials.

2.6 Summary

This chapter explains the challenges of teaching an abstract topic, such as computer science, at a distance, where domain complexity is fashioned by many factors. In particular computer science teaching suffers from rapid change as it seeks to reflect technological progress through an ever-evolving curriculum. Representing information effectively is hampered by continual change as rehearsal of best practice is overtaken by the speed of developments in the discipline. However, the overarching difficulty facing the domain is providing representations that can overcome the complexity of understanding computing artefacts that are abstract dynamic models changing with time.

The difficulties of teaching abstract topics are amplified by distance education. Students are essentially remote learners who study part-time, off-campus with limited time and resources; relying on the home materials to sustain their education. In these situations it is difficult for students to understand abstract, dynamic, and invisible artefacts using static instructional materials, where teacher and student are separate and distant.

As the majority of distance study involves self-study texts, difficult concepts need to be represented as clearly as possible. The development of materials to cope with complex domains and difficult concepts is an ongoing mission for Open University academics. Hence there is a need to investigate how to improve instructional materials in order to address the challenges facing students studying abstract topics at a distance.

Two approaches have been identified as potentially informative in addressing this problem. The individual differences literature provides awareness of the relationship between instruction, learning outcomes and individual traits in learning. The representation literature provides information about the semantic issues, cognitive issues and properties of representation, and their effects on learning outcome. These themes are explored in the next two chapters.

Chapter 3 Individual differences in learning

3.1 Introduction

This chapter examines the literature on individual differences in human learning as a theoretical basis for understanding preferences and learning outcomes when students are exposed to different representations of instructional materials. The individual differences reviewed in this chapter examine learner traits and how they impact on learning and respond to instruction. It does not examine individual differences related to demographic variables or gender. It covers a range of constructs commonly known as cognitive style, cognitive control, and learning style. These are reviewed within the theoretical framework of Curry's (1983) 'onion' model to provide coherence for the reader.

The review examines the hierarchical nature and interrelationships of the individual difference constructs and their theoretical basis, which may impact upon the appropriateness of their use in different contexts. The chapter concludes with the choice and rationale of tests. The Group Embedded Figures Test, the Cognitive Styles Analysis and the Learning Style Questionnaire are chosen to measure individual difference in human learning. They will be used to assess whether individual differences are factors that affect learning when distance students are studying different representations of instructional materials.

3.2 Individual differences in learning

The basis of the individual differences research in human learning began early in the 20th century (Stroop, 1935) and rose in popularity in the '60s and '70s (Curry, 1983;

Riding & Cheema, 1991). Understanding human learning is complex (Dunn, Beaudry, & Klavas, 1989; Emanuel & Potter, 1992; Geiger & Pinto, 1991) as individuals differ in their cognitive 'tool-kits', whether conscious or sub-conscious, from which they draw their learning repertoires. As individuals, students have different learning traits, capabilities and motivation, and their nature of thinking and their processing of a task may vary (Dunn et al., 1989; Grasha, 1984; Jonassen & Grabowski, 1993; Pask, 1976). Hence learning is multifaceted and difficult to understand.

This complexity is reflected in the many and varied perspectives reported in the literature on individual differences in learning, which is neither coherent nor consistent (Curry, 1983; Grigerenko & Sternberg, 1995; Lewis, 1976; Messick, 1987; Miller, 1987; Riding, 1998; Riding & Cheema, 1991). "Chief among these difficulties is the bewildering confusion of definitions surrounding learning style conceptualisations, and the concomitant wide variation in scale or scope of behaviour claimed to be predicted by learning style modes" (Curry, 1983, p4). Part of the problem lies in researchers working in isolation and failing to acknowledge the existence of other types of styles (Curry, 1983; Riding & Cheema, 1991). It is further complicated by the fact that researchers use different terms to encompass individual differences in human learning such as cognitive control, cognitive style, learning style, which makes the reporting of the literature difficult.

Jonassen and Grawboski (1993) use an approach that categorises individual differences in learning in terms of cognitive controls, cognitive styles and learning styles. For example, they define cognitive style as "how we interact with our environment, extract and perceive information from it, and reflect and organise the knowledge that we have acquired" (p173). This is an *information processing* perspective in which the style is measuring how an individual interacts with external stimuli from the world. Here are some examples of cognitive style (see Jonassen and Grawboski (1993) for further details):-

- visualiser/verbaliser
- visual/haptic
- levelling/sharpening
- serialist/holist

Cognitive controls are not universally recognised as being distinct from cognitive styles (Squires, 1981). However, Cotugno (1983), Messick (1984), Santostefano (1986), and Jonassen and Grawboski (1993) perceive cognitive controls to be different. Jonassen and Grawboski define cognitive controls as follows: "They represent patterns of thinking that control the ways that individuals process and reason about information. Each cognitive control represents a separate landscape or pattern of thinking" (p83). This is a *cognitive processing* approach where the cognitive control describes how an individual reasons about information and structures it. It does not relate to information processed from external stimuli but how an individual organises information internally in order to understand it.

Jonassen and Grawboski classify the following as some examples of cognitive control:-

- Field independence
- Field articulation

- Cognitive tempo
- Focal attention
- Category width
- Cognitive complexity
- Strong versus weak automatizer

Learning style is often used as a metaphor for considering the range of individual differences in learning and may include the separate genres of cognitive styles, cognitive controls, learning styles, and approaches to learning (Entwistle, 1981; Riding & Cheema, 1991). Jonassen and Grawboski (1993) describe the separate genre of learning styles as: "applied cognitive styles, removed one more level from pure processing ability" (p233). This is an educational perspective where educators in the early '70s began to develop measures of individuals' preferences towards learning. Some examples of learning style inventories are

- Kolb's Learning Styles Inventory
- Gregorc Learning Styles Inventory
- Honey and Mumford's Learning Style Questionnaire
- Grasha-Riechman Learning Styles Inventory

Cognitive styles, cognitive controls and learning styles have contentious interpretations and relationships with each other. However there is a body of knowledge that suggests a hierarchy between these genres. Curry (1983) provides a useful model that illustrates the integration and hierarchy of these different genres.

She refers to the three genres as instructional preference, information processing style, and cognitive personality style.

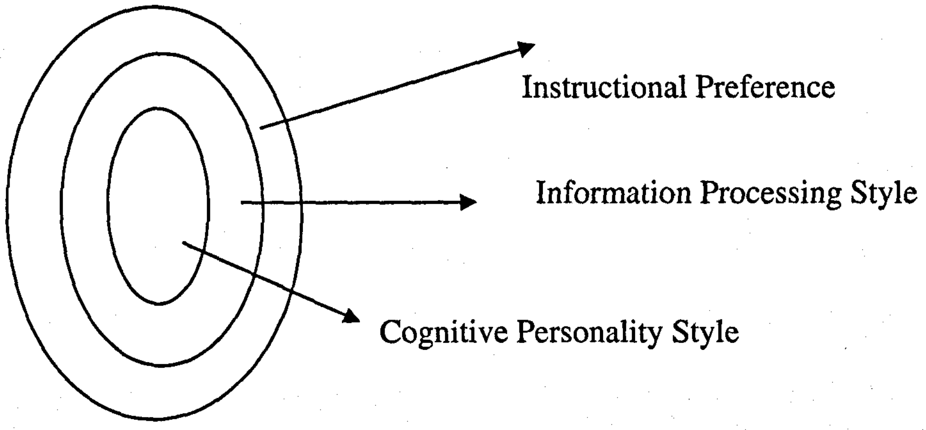


Figure 3.1 Curry's Onion Model (1983, p19)

Cognitive personality style is the inner-most layer of the onion, which relates to more fundamental and internal cognitive processes, less modifiable via instruction. The next layer of information processing style relates to how an individual prefers to process information from external stimuli. These are relatively stable, but yet still modifiable. They are influenced by the inner layer of cognitive personality style and in turn influence the outer layer of instructional preference. Instructional preference characterises the environment in which the student prefers to learn. This is influenced by the former two genres but is the least stable of the traits.

Precursors to Curry's theme of hierarchy were Santostefano (1978), Cotugno (1983), Messick (1984), and Miller (1991). Messick proposed a hierarchy where cognitive controls, similar in genre to Curry's cognitive personality style, were the overarching control structure. He defined these in a similar way to Curry as innate less modifiable traits that managed lower order abilities such as cognitive styles, considered as more modifiable traits. Cotugno (1983) similarly hypothesised that cognitive controls form a hierarchical structural arrangement. Santostefano (1978) proposed a framework where cognitive controls and styles were defined as hierarchical in nature where cognitive controls were also superordinate. Miller (1987) likewise postulated some degree of hierarchy in relation to learning styles.

Vermunt's (1998) integrated model also involves a hierarchy of layers in an individual's approach to learning. Vermunt's aim was to encompass aspects of existing models and research to demonstrate an integrative model of constructive learning processes in one inventory (Inventory of Learning Styles), illustrated in Figure 3.2.

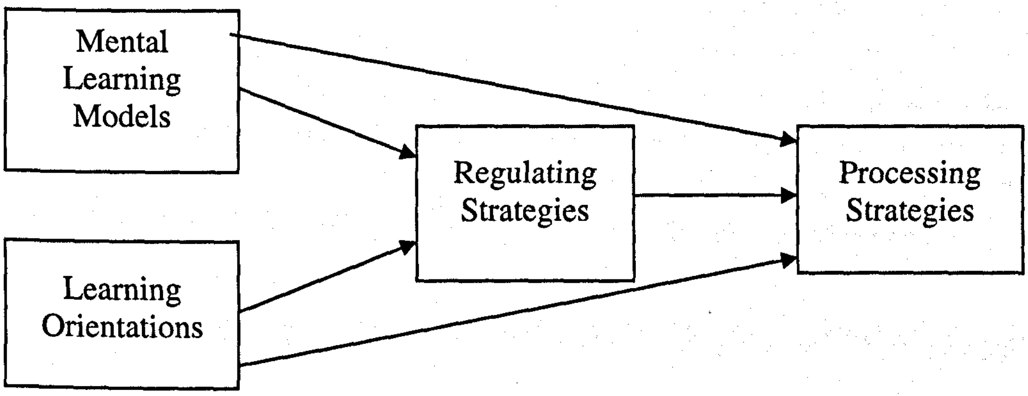


Figure 3.2 Illustrating Vermunt's model (1998, p153)

Mental learning models refer to the conceptions and views that students have about learning and teaching such as the student's own role in learning and the teacher's role. Learning orientations refer to the student's motivations, personal goals and fears about their studies. The cognitive processing strategies are patterns of thinking that enable students to process content. The regulating strategies are metacognitive activities that regulate and control the cognitive processing strategies (Vermetten, Lodewijks, & Vermunt, 1999; Vermunt, 1998). In other words they control or regulate how an individual may process information. Vermunt's model has similarities with Curry's model in that it illustrates a degree of hierarchy. However the ILS inventory is interesting as it includes regulation strategies where there is some sense of a learner's ability to develop strategies to compensate for either fundamental traits or instructional difficulties.

Riding has similarly attempted to provide a model that encompasses other previously researched styles (Rayner & Riding, 1997; Riding & Rayner, 1997; Riding, 1998; Riding & Cheema, 1991). The Cognitive Style Analysis (CSA) takes an integrated approach incorporating fundamental elements of style in the development of a learning style model (Rayner & Riding, 1997; Riding & Cheema, 1991). The Verbal-Imagery scale reflects Curry's information processing style that processes external stimuli. The Wholist-Analytic scale, based on Witkin's field independence style, reflects internal cognitive processes, (Riding & Cheema, 1991), and maps onto Curry's cognitive personality style. However, both Vermunt and Riding lack any accommodation for task and context having an effect on these factors. As Marton and Säljö (1984) report, the context and task affected students' approaches to learning. Laurillard (1978) further reported that students' approaches to learning can also vary within the same task.

Riding and Vermunt's approaches echo the hierarchical nature of Curry's model, which provides a basis for interpreting the individual differences literature as genres or layers that have interrelationships with each other. Although there is contention between the identification of these genres, it seems reasonable to assume that there is some degree of hierarchy. Thus some traits, more closely related to personality, are less modifiable while others are more modifiable, even if the distinctions do not reflect neat categories.

Another factor in the individual differences literature is the theoretical origin of a particular style and its test, as this may have an impact upon context and intended use. For example, Grigerenko and Sternberg (1995) describe three distinct approaches as 'cognition-centred', 'personality-centred', and 'activity-centred'. Cognition- and personality-centred approaches were the fruits of experimental psychologists researching individual differences in personality, perception and cognition (Grasha, 1984; Miller, 1991). Activity-centred approaches, however, were fashioned by educationalists researching learning style and approaches to learning in the classroom (Entwistle, 1981; Jonassen & Grabowski, 1993; Rayner & Riding, 1997; Schmeck, 1983).

These distinctions are indicative of the problems with this literature and research. The difference in perspectives and backgrounds mean that there is a difference in what kind of information is expected from these various approaches and how they might inform the researcher. For example, a psychologist experimenting with cognitive styles may hope to glean some information about underlying trends in cognition and perception, i.e., cognition-centred approach or personality centred-approach. However an educationalist may be more interested in how style research impacts on the practice of learning, i.e., activity-centred approach (Grigerenko & Sternberg, 1995). Additionally, the research may be investigating either a whole educational programme or specific aspects of instruction, i.e., 'practice-oriented' approach (Laurillard, 1978). Therefore understanding these differences may provide information about what any psychometric test or research approach might offer and in what circumstances it might be useful.

There are two main conclusions in this section. First the individual difference genres are hierarchical in nature and different tests may be testing different layers or levels of an individual's approach to learning. Second the different theoretical basis may impact upon the appropriateness or effectiveness of use as a tool to investigate an individual's approach to learning. Some may not be suitable for assessing an individual's approach to learning on a given task as they may be designed to measure general orientations.

In the following sections Curry's model is used to review the more familiar nomenclature of cognitive styles, cognitive controls and learning styles, where they are mapped onto Curry's model for clarity.

3.2.1 Cognitive Personality Style

The definition of cognitive controls is closely linked with Curry's layer of cognitive style personality. Cognitive controls are derived from mental abilities that form patterns of human thinking or reasoning in individuals (Jonassen & Grabowski, 1993). Each cognitive control represents a separate pattern of thinking. They are somewhere between mental abilities and styles in that they do not represent true abilities but are style-like in that they are concerned with the process and construct of learning (Cotugno, 1983). This definition mirrors the cognitive personality style layer in Curry's model, where it relates to more fundamental traits of internal cognitive processing.

However, using the terms cognitive control to describe a genre is problematic as some researchers do not acknowledge its existence, which is why Curry's model provides a useful framework for review purposes. For example, Witkin et al. (1977) refer to field independence as a style while Jonassen and Grabowski (1993) regard it as a cognitive control. However a more important issue is what the construct is actually measuring. Field independence is

> the extent to which the person perceives part of the field as discrete from the surrounding field as a whole, rather than embedded in the field; or the extent to which the organisation of the prevailing field determines perception of its components; or, to put it in everyday terminology, the extent to which the person perceives analytically (Witkin et al., 1977, p 6-7)

This means that field-independent learners can re-organise the information internally to their own choosing and are not influenced by the structure imposed by the stimuli. Witkin et al. also hypothesised that field independence is a stable personality trait (Witkin, Goodenough, & Karp, 1967). Hence it is associated with more ingrained attributes, such as personality, allowing field independence to be considered in Curry's category of cognitive personality style.

3.2.2 Information Processing Style

The definition of cognitive styles can similarly be mapped onto the information processing style in Curry's model. Cognitive styles are preferences that reflect underlying personality traits. They are considered consistent traits that reflect how an individual perceives and interacts with their environment. (Jonassen & Grabowski, 1993, p173; Messick, 1984, p61). Cognitive styles effect the way in which learners process information. They differ from an ability measurement, as they are not value laden. This reflects Curry's definition of information processing style, where it relates to the processing of external information.

The measurement of cognitive styles is either typical or contrasted performance. It is bipolar where neither end of the pole has any benefit over the other; the poles simply indicate how a person prefers to receive and process information within the dimension. Most individuals are somewhere on the continuum between both poles where neither pole has any higher order value in learning than the other, they simple describe different preferences for processing information.

An example of a cognitive style that fits within the information processing genre of Curry's model is the Imager/Verbaliser dimension in Riding's (1997; 1998) Cognitive Styles Analysis. This measures the degree to which an individual prefers to process verbal or visual information from external stimuli. Neither pole is intrinsically more advantageous than the other; they merely indicate information processing preferences, although they could differ in their value in potential tasks.

3.2.3 Instructional Preference

Mapping Curry's model between learning style and instructional preference is more difficult than with the other areas of individual difference research reviewed so far. Curry (1983) defines instructional preference as "the layer that interacts most directly with learning environments, learner expectations, teacher expectations and other external features, we would expect instructional preference to be the least stable, the most easily influenced level of measurement in the learning styles arena" (p11). This is similar to Jonassen and Grabowski's view of learning styles in that they regard learning styles as "self-reported internally consistent constructs of themselves as learners" (p234). There is similarity also between their categorisations. Jonassen and Grabowski categorise the Grasha-Riechmann Learning Styles inventory within the learning styles genre and similarly Curry categories this same test within her instructional preference layer. However, there are also differences in perspective. Jonassen and Grabowski categorise Kolb's Learning Styles within the learning style genre while Curry categorises it within her information processing layer. Jonassen and Grabowski's criteria for categorising learning styles tends to hinge on the self-reporting nature of inventories that do not measure skills or abilities.

Another example of this is where Entwistle has mapped Pask's (1976) cognitive styles onto learning styles. "The 'holist like' style is called *comprehension learning* which involves 'building descriptions of what is known'. The 'serialist like' style is called *operational learning*, which is "the facet of the learning process concerned with mastering procedural details". (Entwistle, 1981, p93).

The tools used to assess learning styles are less specific than those used in cognitive styles and cognitive controls. They do not test skill, ability or preferred processing tendency but report on how the individual thinks they prefer to learn (Jonassen & Grabowski, 1993). The primary use of these results is as a guide for instruction and evaluation. However, the validity of the learning style inventories is based on the assumption that learners can accurately and consistently reflect (i) how they process external stimuli and (ii) how they model internal cognitive processes. The efficacy of the results is based on the individual's ability to accurately and consistently report upon themselves. As a research tool the validity of these psychometric measures is controversial (Grasha, 1984; Jonassen & Grabowski, 1993).

Learning style paradigms may differ, nonetheless they are based on relevant psychological and pedagogical theory and have validity in terms of cognitive ability and styles as benchmarks. Jonassen and Grabowski (1993) purport that "*the primary use of learning styles is as a metaphor for thinking about individual differences*" and while convergence between tools is debatable they still have merit in aiding understanding individual learning processes and preferences (Miller, 1991).

3.3 Issues relating to individual differences research

Early distinctions between perspectives were made by Messick (1987) offering some explanation of the difference between cognitive styles and cognitive controls. This was based on the testing nature of the construct. Cognitive style measures are bipolar and have qualitatively different implications for the individual. In contrast, cognitive controls measure ability based on maximal performance (Messick, 1987). However, the nature of the test itself is not necessarily an appropriate distinction between style and control as it only reflects how the test was designed. Part of the confusion is due to cognitive control and cognitive style terms being used interchangeably (Santostefano, 1978) therefore eroding critical distinctions between levels and types of information processing. This is where Curry's framework offers a more reliable basis for distinction as it is devoid of historical nomenclature.

Cognitive styles and cognitive controls both describe and measure how individuals interact with their environment and make sense of it. Santostefano (1978) succinctly describes them both as information processing strategies that subscribe to different models, and this perspective fits within Curry's model. It is the underlying information processing style, whether internal where the individual organises information in the brain, or external, where the individual organises the processing of external stimuli, that separates these two distinctions.

Much of the cognitive style research implies that preferences measured by individual difference inventories are stable across domains (Jonassen & Grabowski, 1993). Squires (1981) argues that these may be interpreted as preferences for simplicity in some tasks and complexity in others, depending upon the task or level in life. Squires describes this as the *invariant central process paradigm* in that processes may vary with task, stimuli, sensory modality or environment, which is what Laurillard (1978) also found.

The issue of stability across domains may be related to the circumstances in which the construct and its associated inventory are used. For example, consider a style and its inventory that is based on a cognition-centred approach, developed in an artificial experimental situation. If this inventory was used to predict a learner's performance on a task in a context specific learning episode, then it could explain why results would vary in different learning domains and contexts. Inventories developed in artificial laboratory settings may only be able to indicate generic tendencies or preferences rather than task specific ones.

Additionally there is little longitudinal research across domains to support the claim that styles are persistent. Most style research is conducted with younger undergraduates or graduates rather than mature students or the general population, thus results may not be generalizable (Squires, 1981, p8). Witkin et al. (1977)argues that styles are stable, but Geiger, Pinto and Goldstein have shown changes in Kolb's learning style over time (Geiger & Pinto, 1991; Goldstein & Chance, 1965; Pinto, Marshall, & Boyle, 1994).

The difference in perspective of individual difference constructs can impact on validity. Messick (1987) views learning styles as strategies that can be attuned to particular types of tasks and situations. In contrast, Schmeck (1983) conceives learning styles as applied cognitive styles that are relatively consistent predispositions to adopt particular learning strategies across specific tasks and domains. The difference in opinion between Messick and Schmeck could be explained by the confusing use of terms and lack of clarity about what inventories are measuring. For example are inventories measuring ingrained traits or internal or external processing predispositions? Squires (1981) argues that the lack of concurrent instrument validity may not be due to instrument error but in construct definition; constructs that reputedly measure the same construct may actually be measuring different constructs.

One distinction in learning style inventories is between their theoretical basis on either personality or learning (behaviour-process). The theory of personality-centred learning styles is that predispositions in learning stem from more inherent traits such as personality. The theory of learning-centred learning styles originates from observing behaviours in the learning process. In the personality approach, personality is the overriding factor in an individual's predisposition to use a particular learning style.

Jung's writings have been the theoretical basis for some of the learning style inventories: examples include the Myers-Briggs, Kolb's, and Honey and Mumford's. Miller (1991) points out the inconsistency within Jung's personality theory. One problem with Jung's dimensions is the lack of clear separation between conative and cognitive elements (Coan, 1979; Forisha, 1983). As a conceptual basis for learning styles the consistency of Jung's theory is arguable (Miller, 1991).

The learning-centred approach (behaviour-processing) examines performance on a task as an indicator of predisposition in learning approaches. Most of the literature reviewed so far examines learning in relatively artificial experimental contexts. Marton and his colleagues (Marton & Säljö, 1976; Svensson, 1977) took a different approach as they were concerned that experimentally based inventories could not reflect how students perform tasks in normal academic situations. Marton examined students' activities during a learning task using an introspection method. He gathered retrospective accounts of students' learning processes. He found that students adopted either a deep or surface approach to learning, adopting different strategies depending upon the content, the context and the perceived demands of the task (Marton & Säljö, 1976). Laurillard argued that these were not different individual characteristics of students but were related to the nature of the task and context (Laurillard, 1978).

Lewis (1976) argues that if personality and cognitive style underlie learning styles then both should be studied in relationship to learning with the emphasis on more basic observable individual differences. However, efforts in this area have not been informative (Schmeck, 1983). Schmeck and Entwistle favour the learning-centred approach. Schmeck argues he is only interested in learning, which is why his model is based around learning. Although, he suggests that using both personality and cognitive approaches offer complementary and converging research on the fundamental theme of styles from the learning perspective.

While the approaches discussed have been used to develop learning style inventories that are scalable tools to assess student's learning approaches, they still suffer from validity issues. This rests on an individual's ability to self-report accurately. Argyris

(1976) argued that there is a difference between what an individual reports they are doing, i.e. *'espoused theory'* and what they actually do, i.e., *'theory in use'*. The self-reporting techniques of learning styles place more reliance on *'espoused theory'* than *'theory in use'*. One method of overcoming this is to adopt Marton's approach to investigating an episode of learning. However this can not easily be administered to large numbers of students.

As a method of considering the differences between the various perspectives and goals of the individual differences in learning research, a matrix has been devised in this section to indicate relative distinctions (see Table 3.1). It shows the theoretical basis for each genre of individual difference styles.

Table 3.1 illustrating the mapping between different approaches and their goals

	Cognitive Personality Style (CPS)	***Information Processing Style (IPS)***	***Instructional Preference (IP)***
Cognition-centred Approach	Examines underlying cognitive traits in internal cognitive activities	Examines underlying cognitive traits in information processing of external stimuli	Extrapolates from CPS and IPS adopting a cognition perspective to predict preference in instruction
Personality-centred Approach	Examines underlying personality traits and how they influence internal cognitive activities	Examines underlying personality traits and how they influence information processing of external stimuli	Extrapolates from CPS and IPS from a personality perspective to predict preference in instruction
Activity-centred approach		Examines learning processes and observes behaviour to predict information processing of external stimuli	Examines learning processes and observes behaviour to predict students preference in instruction

Table 3.1 illustrates that the interpretation of the genre of style may be dependent upon its theoretical origin. Therefore particular constructs may only be useful in certain circumstances where there is some match between the type of research being conducted and its theoretical basis. For example an instructional preference test that is based on an activity centred approach may be suitable for assessing particular behaviours in learning. However there is limited information about the results of such an approach where application and theoretical base are matched or whether inventories examine general- or task-specific approaches to learning. The literature has not provided a great deal of understanding on this and general versus specific use is still an issue.

There are reliability, validity and stability issues to be considered when interpreting results from style inventories. However, despite these aspects, using individual difference inventories are still worthy of investigation. First, there are links between the representation of information and how individuals prefer to process information. Research using style inventories to examine the effects of visual representations may provide knowledge of their appropriate use as well as their value. Second, style research is again re-emerging as a popular theme in education, particularly in designing individualised instruction for the web (Aguilar & Kaijiri, 2002; Sampson, Karagiannidis, & Strintzia, 2002). Therefore it is important to have further and more current research on the value of using style inventories to inform present and future developments in education.

3.4 Choosing individual differences tests for assessing learning in computer science students

The reasons for selecting the individual difference measurs used in this thesis were more pragmatic than theoretical. The field independence construct and its associated measure was chosen because computer science requires students to develop structure. It was assumed that field independence might be indicative of preference and performance by computing students who are required to structure complex abstractions during programming.

The Imager/Verbaliser construct and its associated measure was chosen because there was a special interest in how students reacted to instructional materials that contained visual representations. It was expected that Imagers would have a greater preference for and perform better when instructional materials contained visual representations.

The third individual difference test was Honey and Mumford's (1992)Learning style Questionnaire and chosen to assess a learner's preference towards particular styles of study. It was a learning style measure that was being used with computer science students at the Open University and more information was required on its value in this context. It had previously used in another study (Carswell, Thomas, Petre, Price, & Richards, 2000) but was not found to be useful. Part of its continued usage was to assess whether it was useful in this thesis and whether previous results were as a result of the nature of the study.

The three measures chosen were also used to assess more generally their usefulness in researching specific learning episodes in a distance education context. The following sections review the measures chosen in more detail.

3.4.1 Using the Group Embedded Figures Test to Measure Field Independence

The Group Embedded Figures Test (GEFT) (Witkin, Oltman, Raskin, & Karp, 1971) is used to measure field independence. Field independent individuals create their own structures in learning while field dependent individuals rely on imposed structure (Richardson, 1998b; Witkin & Goodenough, 1981; Witkin et al., 1977). The Group Embedded Figures Test (GEFT) is administered on a group basis as an extension of the Embedded Figures Test, which is administered on a one-to-one basis.

Both of these tests originated from Witkin's Rod-and-Frame test, which measured how an individual oriented themselves in space. This test focused on the relationship between an individual's visual and kinaesthetic cues. The dependence on visual cues led to the construct of field independence. Witkins and colleagues later found that a test created by Gottschaldt correlated positively with their Rod-and-Frame test. As a result Witkin and colleagues developed the Embedded Figures Test to examine the construct of field independence, which requires individual participants to identify a simple figure in a more complex one. The results from the Rod-and-Frame test were found to correlate with the Embedded Figures Test (EFT). The GEFT works on a similar basis except the participants are tested in groups. Participants are required to complete a booklet on a timed basis. This involves tracing a simple figure embedded in a more complex one.

This test has been chosen to assess an individual's ability to create their own structure and this is an important skill in computing. Field independence would be an indication of their ability to structure abstract concepts into successful processes. It also has special significance for the domain of computer science as science and engineering students are reported to be more field independent. Guster and Batt (1989) found the GEFT significant ($r = 0.3965$, $p < 0.01$) in predicting the student's percentage score on the final exam in microcomputer use. Stevens (1983) found significant correlations ($r = 0.40$, $p < 0.001$) between the GEFT and an achievement score gained from a combination of a general computer literacy score, and a computer knowledge and Basic programming score. Werth (1986) found the GEFT significant ($r = 0.317$, $p < 0.01$) in predicting success in a first year computer science course using the Pascal programming language. Chamillard and Karolick (1999) also found the GEFT useful in predicting performance on an introductory computer science course.

Field independence has also been claimed to have special relevance for distance education. Moore (1976) found that distance education students had higher scores on field independence compared with normative groups. Thompson (1984) conducted a similar study and found that distance education students had relatively high scores in field independence compared with normative groups. These studies indicate that this test might be useful in predicting preference and learning outcomes in different representations in instructional materials for computer science students studying at a distance.

3.4.2 Using Cognitive Style Analysis to Measure Imager/Verbaliser

Cognitive Style Analysis (CSA) measures an individual's general processing traits (Riding, 1998). These include the internal cognitive processing and external processing of stimuli. There are many constructs that address these factors, however, Riding and Cheema (1991) found that these could be grouped into two principal cognitive dimensions: Wholist-Analytic and Verbal-Imagery (Rayner & Riding, 1997; Riding & Rayner, 1997). The Wholist-Analytic dimension measures whether an individual is predisposed to organise information into wholes or parts and the Verbal-Imagery dimension assesses whether an individual has a tendency to process verbally or in images (Riding & Cheema, 1991).

This test was chosen to assess preferences and learning outcomes associated with different representations of instructional materials for students, i.e, visual and verbal. The test measures performance on simple tasks that are assumed to be generally representative of an individual's processing traits. It is appealing for a wide range of uses as it is context free, does not contain difficult language, and is not questionnaire-like and burdened with self assessment reliability issues.

There were no studies found of this being used in a distance education context. However Salder-Smith and Riding (1999) have used this test to investigate the relationship between learners' styles and their instructional preferences. They found that Wholist-Analytic dimension revealed a significant effect on instructional preference with Wholists having a stronger preference for non-print media. Riding et al. (1989) and Riding and Douglas (1993) also performed studies in the relationship between modes of representation and the Verbal-Imagery dimension. Both studies showed that Verbalisers preferred textual materials while Imagers preferred non-textual modes. They infer it is possible to predict representational preference based on the verbal-imagery score. In short, the CSA tool has a history of positive results with different representations (e.g. textual versus visual).

3.4.3 Learning Style Questionnaire

Honey and Mumford's (1992) Learning Style Questionnaire (LSQ) indicates a measure of an individual's orientation towards four modes of learning style. The orientations are broadly equivalent to Kolb's (1975) account of experiential learning. The styles are: *Activists, Reflectors, Theorists,* and *Pragmatists.*

- Activists like new experiences and immediate tasks, thrive on challenge, and are bored by implementation. They learn by doing.
- Reflectors review experiences, analyse thoroughly before concluding, and can postpone decision-making. They learn through reflection.
- Theorists are assimilators, tidy and rational, adapting observations into theories. They learn from systems, models, and concepts.
- Pragmatists are 'ideas people', who put theories into practice, like decision making, and problem solving. They learn by practical application of theory.

The LSQ is a self-reported learner preference questionnaire and its validity relies on the ability of individuals to accurately and consistently report upon themselves. The LSQ has previous been used to assess preference between traditional and electronic distance education environments, although it was not useful in this context (Carswell et al., 2000). However, Sadler-Smith (1997) conducted a study on a battery of questionnaires and results showed that good performance was associated with high scores on the Theorist scale. Other studies in education management (Seymour & West-Burnham, 1989a, 1989b) showed that there was a significant level of accuracy in the ability of the sample group to predict learning styles. Allinson and Hayes

(1988; 1990) have shown that the LSQ has adequate test-retest reliability and construct validity.

3.5 Conclusion

Reviewing the individual differences in human learning literature is complicated due to the variety of constructs and the variability between them. Curry's model offers a way to examine these constructs that is devoid of historical nomenclature and the review shows that other models, such as Vermunt's and Riding's share similar perspectives on the hierarchical nature of styles.

The literature failed to provide information about either the general or specific use of style inventories in learning situations. These factors may have contributed to some of the reliability, validity and stability issues in individual tests. As many of the tests have been used in artificial experimental situations, their practical application for the practice of improving learning is unclear.

Despite some of the negative aspects reported in this review on the use of styles, there is a relationship between visual representations and how individuals process them, that is worthy of investigating using individual difference inventories. Additionally individual differences are re-emerging as popular themes in education, particularly in individualising learning on the web. Therefore there still remains a challenge for educational technology research in gauging the value of individual differences tests in general or specific learning contexts. They are used in this thesis to examine their value as well as the circumstances in which they are valuable.

The Group Embedded Figures Test was chosen to assess an individual's ability to provide their own structure. The expectation was that this would indicate preference and performance of computing students. The Cognitive Styles Analysis was selected to measure an individual's preference and performance when studying instructional materials containing visual representations. The expectation was that Imagers would prefer visual representations and benefit from them more than Verbalisers. The Learning Style Questionnaire was chosen to assess a learner's preference towards particular styles of study. Additionally, it was a test currently being used in the computing department with students; more information was required on its usefulness in this context. In interpreting the results from these tests, the issues raised in this review, such as suitability in practice oriented situations, will be taken into account.

Chapter 4 Representation

4.1 Introduction

This chapter examines some of the issues involved in representing instructional materials for students studying at a distance in the computer science domain. The literature on representation is reviewed to provide knowledge of cognitive and semantic issues, as well as the properties of representations. Cognitive processing theories are examined and used to explain how visual and verbal representations are dealt with. The properties of representations are examined to explore differences in use and to explain inconsistencies in results. A relatively crude approach is proposed that distinguishes between representations in terms of their processing factors and properties. Implications of the literature are discussed within this framework to enable meaningful comparisons between results and in order to make valid inferences.

4.2 Rationale

Students who are studying computer science at a distance are faced with two main challenges. First, there is the complexity of learning in an abstract domain and, second, there is the challenge of studying at a distance. These also present challenges for academics who are developing instructional materials to accommodate both educational modality and domain complexity. How to represent information in a coherent way for a range of diverse learners is always a challenge, but in the distance education context the problems are amplified due to the demands of producing coherent stand-alone self-study texts to explain complex concepts. There are several issues.

First, there is an understanding of student preference for representation. Academics, experienced in producing self-study texts, may be influenced by their own level of understanding and instructional needs as opposed to being led by student preferences. Their own perspectives may unconsciously inform the development of instructional materials. Secondly, representing information in a student's preferred way could arguably help them learn more effectively. Good instruction is clearly organised and structured (Hartley, 1998) and it could be that academics are less aware of student needs as they have forgotten what it is to learn (Durbridge, 1995). Also academics are usually the most successful students and they probably required less instructional support during their own studies than the students they now teach.

The effect of using different representations in computing for distance education has received little attention. These reasons motivate the investigation into representation in this context. This literature review examines the semantic and cognitive issues in representations, properties of representations and implications.

4.3 Semantic issues

Representation is a coding system for expressing something in the real world. "This description implies the existence of two related but functionally separate worlds: *the represented world* and *the representing world*" (Palmer, 1978, p262). The representing world maps on to the represented world in some fashion where not all aspects of the represented world need to be modelled. The role of representation in instructional materials is to communicate domain knowledge in a precise, manageable, and engaging way for learners. Choices can depend upon a variety of factors such as purpose, task characteristics, and activity times. Knowing what type of representation to use and when it is appropriate is a complex issue (Booher, 1975).

One of the principal aims in deciding how to represent information is understanding how effective it is for the learner (van Someren, Reimann, Boshuizen, & de Jong, 1998). Key issues in representational design choices are their adequacy for conveying the information and their cognitive cost for the learner. The choice may depend on the representation's 'affordance', where affordance is an aspect of the representation that makes it obvious how it should be used (Norman, 1988; Reber & Reber, 2001).

For example, visual representations, such as diagrams, may be easier and more intuitive representations of information flows and inter-relationship between entities than expository text (Larkin & Simon, 1987; Rohr & Reimann, 1998). Text primarily affords propositional representations where information can be expressed in indicative sentences and concepts are communicated in an explanatory manner. Tables provide a systematic and orderly arrangement of items that capitalise on juxtaposition properties (Hartley & Yates, 2001). Formulae succinctly describe mathematical functions while graphs can visually show trends in data sets. In short, there are representations that lend themselves to particular types of information representation.

Visual representations have perceptual and spatial properties that are powerful and easy for novices to comprehend (Winn & Holliday, 1982). They are good for conveying ideas that need to be considered simultaneously and allow individuals to make multiple distinctions easily (Hartley, 1994). Visual representations are intuitive to use where humans can make valid inferences from them and they are of equivalent value to verbal representations (Sloman, 1971). They support automatic perceptual inference because the indexing of the information can support useful and efficient computational processes (Larkin & Simon, 1987). For example, it is more efficient to 'read' a map as a representation of a country than to read a verbal explanation of its geography. A map provides a range of spatial and relational information that can be used in a variety of ways for a variety of purposes, e.g., navigation, comparison of distances, graphical features. In comparison a verbal description of a country could not offer the same multiplicity of use.

Visual representations work best when they are an integral part of the text (Mayer, 1989; Woudstra & Terlouw, 1992) and when the mapping between the representation and meaning is analogous to perception of the real world (Dobson, 1998). A common finding is that novices, with less experience in a domain, benefit from visual representations (Cronbach & Snow, 1977; Mayer, 1997; Snow & Yalow, 1982). However, there are also dissenting views on the use of visual representations and these will be discussed later in this section.

Visual representations have played important roles in reasoning and have enabled notation to specify abstractions (Meuller, 1969). Many eminent scientists, such as Einstein and Faraday, claim to have thought visually (Larkin & Simon, 1987; Shepard, 1978). Einstein claimed that his particular ability lay in the visualisation of effects, consequences, and possibilities, and not in defining a mathematical calculation. He only coded his conceptualisation when he could reproduce his mental images and combine them. Similarly, Faraday's modern conception of electric and magnetic fields began as visualisations of invisible lines of force. He had a limited mathematical background and yet was still able to produce mathematical representations of his concepts (Shepard, 1978).

Mental imagery is not a new theme as these influential scientists report. This suggests that non-verbal representations are intuitive for perceiving and thinking (Richardson, 1999b) and explains why they are considered as relatively easy to process and didactically effective.

Using a variety of representations in instructional materials is frequently assumed to be complementary to the other representations used (Ainsworth et al., 1998). However, instructional developers using multiple representations for the same information may not take account of the complementary or conflicting attributes that they may bring and the costs for learners. First, learners must either know or learn the coding mechanisms for each representation. Second, they must understand the relationship between the representation and the information being conveyed. Third, the learner must understand how the representations relate to each other.

Bertin (1981) argues that visual representations only save interpretation time when they are *perceived* as opposed to *read.* He hypothesised that visual representations portraying spatial relations could be perceived in a way that offered fast processing of information as it appealed to the visual processing system. He argued that verbal information appealed to the auditory system as it had to be read and, in effect, heard via an auditory processing system. As a graphic's main function is making relationships among previously defined sets visible (Winn & Holliday, 1982) its immediacy lies in the ability to *see* the relationships, i.e. its ability to be perceived immediately.

Conversely, a graphic that needs to be *read*, one that contains considerable verbal information, has to be perceived over time and can in fact incur a higher ratio of time spent to information retrieved. So unintentionally a graphic could require *reading* as opposed to *perceiving* and might be more efficiently represented as expository text (Bertin, 1981). The different reading and perceiving aspects of visual representations may not be clearly understood by instructional designers and may explain some of the differences in research results. These will be discussed later in this section.

The task of assigning information to a representation is not well understood (Dwyer, 1978), as is evident in representation research in many disciplines (de Jong et al., 1998). Research in the use of multiple representations in instruction has had mixed results (Ainsworth et al., 1998; Dobson, 1998; Mayer, 1989; Mousavi et al., 1995; Petre & Green, 1993; Preece, 1981; Scanlon, 1998).

Preece (1981) found that high school children studying science had difficulty interpreting complex cartesian graphs. In particular she found that students had difficult interpreting the concept contained in a whole graph. Graph interpretation skills were observed not to be intuitive, and she recommended that students need to be taught these skills in order to interpret graphs satisfactorily. Scanlon (1998; 1988) similarly found that novice physicists had great difficulty in interpreting information correctly from a graph and further, had difficulty assimilating information in formulae and graphical representations. She argues that students need support in order to co-ordinate the information in different representations, as it is not automatic.

Petre and Green (1993) examined problems that hardware designers had in reading visual representations used to present abstract diagrams of electronic components. They postulated that interpretation is not intuitive and secondary notation, while useful, rarely has formalised codified conventions that help readers understand the diagram (Petre & Green, 1993).

These dissenting perspectives are contrary to what Paivio (1971) argued in his ‘coding redundancy hypothesis’. He stated that increased performance was directly linked with the number of alternative memory codes available for an item, whether verbal or visual. Therefore the expectation would be that having more than one type of representation, such as visual and verbal, of the same information would be helpful.

Ainsworth et al. (1998) used multiple external representations to teach mathematics to schoolchildren. Computer software was used to provide visual representations of concepts. They argue that using multiple external representations can be confusing as children find it difficult to make referential links between the representations. Thus representations need to be familiar to aid understanding. They note that appropriate representations need to be used for the task. Learners need to be familiar with the representations and how they relate to the domain to be learnt (Scanlon & O'Shea, 1988).

Brna et al. (2001) also mention this as being problematic. Learning a new representation system while learning the domain knowledge makes the task harder for students, especially as some educators assume that the existence of a diagram is sufficient. However Ainsworth et al. had used representations that were all in the same modality and not supported with any expository text or explanation of their meaning or purpose. Thus, the schoolchildren were arguably only receiving input into one processing system. Therefore if they failed to grasp the meaning of this representation there was no alternatively coded representation to offer another path to understanding the concept.

Mousavi et al. (1995) acknowledge the work of Paivio and showed that his hypothesis on dual coding can explain some of the effects of using multiple representations. They found that using multiple representations that were visual and verbal was beneficial to learning compared to providing information in a unitary mode. They hypothesised that using modes which appealed to different processing systems such as Paivio's (1971) could reduce the effects of 'split attention' where processing incurs cognitive overload as it tries to process information within a single mode. Mayer's (1991; 1992; 1989; 1990; 1994) work similarly showed that using annotated diagrams supported with expository text was beneficial to learning when compared with expository text with no diagrams.

This finding is additionally supported by earlier work of Booher (1975) and Dwyer (1978). Booher found that primarily pictorial-based representations of materials, which were integrated with print, enabled faster performance on tasks compared with primarily print-based materials, even those including pictures. Dwyer found that visual representations could be used to improve student performance in achieving specific educational objectives.

Some reviews of large numbers of studies of the effects of illustrations in texts revealed that an overwhelming majority of the results showed significant improved comprehension in learning (Levie & Lentz, 1982; Levin, Anglin, & Carney, 1987; Levin & Lesgold, 1978). Illustrations appear to aid the recall of the information they illustrate but not other non-illustrated text (Hartley, 1994). Lawless (2000) studied the use of illustrations in two Open University Science courses. He reported that students valued illustrations in text highly as aids to learning. They were able to effectively discriminate between illustrations that were helpful and those that did not contain relevant and useful information. He argues that illustrations need to be taken seriously at the design stage for teaching texts at every level.

Representational choices made by writers of instructional materials appear to be more instinctive than prescriptive (Dwyer, 1978), relying more on intuition than formalised guidelines (Sloman, 1971). There is little evidence of visual representational choices being informed by student's preferences or learning experiences, although Hartley (1995; 1999) has researched the design and layout of textual materials, including research with distance education students.

There are also difficulties in comparing the results of studies. First the nature of the representations is not defined and inconsistencies may be due to differences in representational properties that either exploit or squander perceptual qualities. Second, the domains in which the studies are reported differ and this may explain different effects reported. For example, Mayer's research used illustrations related to concrete real world observable objects. Comparatively Scanlon and Preece's research used graphs conveying abstract unobservable concepts.

Insight into using different representations effectively depends upon understanding cognitive processing and properties of representations and their effects on learning. Hence there are two further issues that need to be explored. One is to examine how representations are cognitively processed and how this impacts on learning. The other is to understand the properties of representations and how they might impact on learning. The next two sections explore these issues.

4.4 Cognitive issues

This section reviews how representations affect the cognitive processing of information and how this impacts on learning. Paivio's (1978) theory of dual coding offers some explanation for the processing of different representations.

> [This] *is based on the general view that cognition consists of the activity of symbolic representational systems that are specialized for dealing with environmental information in a manner that serves functional or adaptive behavioural goals (Paivio, 1986, p 53).*

This non-unitary view of cognitive theory is shared by others (Baddeley, 1992; Bertin, 1983; Mayer & Anderson, 1991; Mousavi et al., 1995; Penny, 1989). Paivio theorises that information is processed by two separate, but richly connected, symbolic systems, i.e., the verbal system and the non-verbal system (see Figure 4.1). The non-verbal system specialises in dealing with perceptual information, i.e., non-verbal objects and events, while the verbal system deals with linguistic information, i.e., concepts, ideas and explanations conveyed using numeric or alphabetic symbols (Paivio, 1979). Thus information can be processed simultaneously by both coding systems.

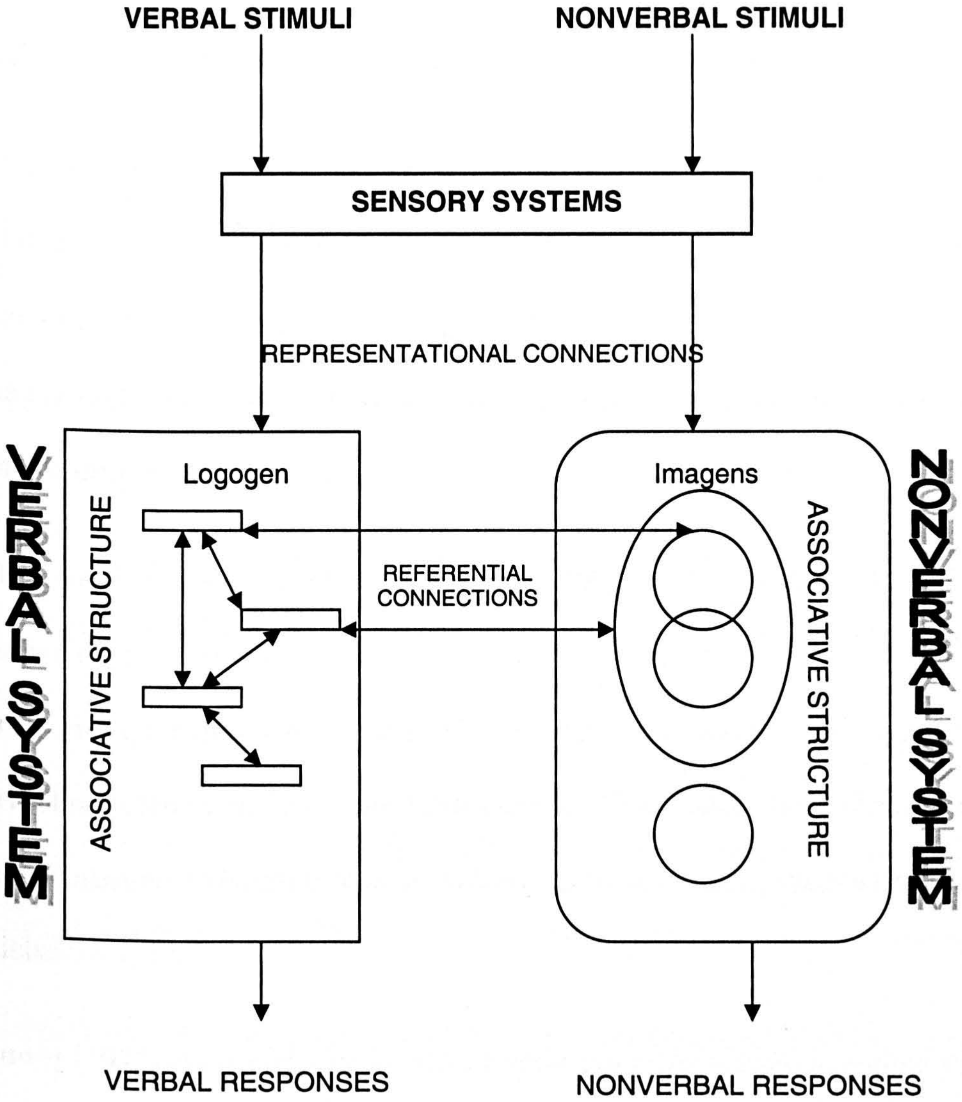


Figure 4.1 Diagram of Paivio's (1986) Dual coding Framework, p67

Figure 4.1 illustrates how verbal information and non-verbal information are processed by two separate systems with connections between them. There are three levels at which information may be processed: *representational*, *referential* and *associative* (Paivio, 1986; Richardson, 1980).

At the *representational* level a symbol arouses the appropriate representation in long term memory such that words trigger verbal representations and perceptual experiences trigger image (visual) representations. The activation of these is relatively direct in that it is affected by modality. Hence a diagrammatic representation and a verbal representation are processed by the two different processing systems.

At the *referential* level symbols in one representation system will arouse symbols in another system (i.e., verbal stimuli arouse representations in the non-verbal system and vice versa). Thus components perceived as visual representations would trigger the naming conventions for those symbols in the verbal system linking the internal information in both coding systems.

The *associative* level enables connections within a coding system such that a non-verbal image in a representation will trigger a non-verbal image of a related situation in the visual coding system. Similarly a verbal representation will trigger another verbal representation, i.e., a word association. This enables links between unfamiliar representations to familiar representations within the coding system (Paivio, 1978; Richardson, 1980).

Bower (1972) disagreed with Paivio's hypothesis of two separate coding systems. He argued that the same relational principles could be applied to both visual and verbal information. He postulated that a common code theory, where individuals have a common generative grammar, underpins the encoding of visual and verbal information.

Pylyshyn (1973) argued against imagery completely as a qualitative distinct or theoretically adequate form of mental representation. He suggested that a third non-externalisable, abstract and propositional coding system would be able to exchange information from verbal and visual codes as required. That is, all information would be coded into this abstract propositional format.

Kosslyn and Pomerantz (1977) rejected Pylyshyn's ideas and argued that the imagery hypothesis was at least as adequate as the propositional one. They found the hypothesis of a third code unconvincing, as transformational rules would be required for verbal and visual information that would not equate to the real world. Consequently the dual code hypothesis would be more economical for this procedure.

Kosslyn (1980) later argued that a series of subsystems could deal with the storing of information about an image. Thus an image has two components: one stores surface level features and the other stores deep representations in long term memory. He specified processes for generating, evaluating and transforming images according to his model. An important aspect in this model is the ability to access information in propositional form. Hence the solution to a question would be a 'race' between the imaginal and propositional information (Richardson, 1999b).

There is considerable support and empirical evidence that imagery is a qualitatively different construct for processing and storing information (Kosslyn, 1980, 1994; Kosslyn & Pomerantz, 1977; Mousavi et al., 1995; Paivio, 1971, 1978, 1979, 1986; Richardson, 1977a, 1977b; Richardson, 1980, 1999a, 1999b; Shepard, 1978; Thagard, 1996). Using Paivio's (1978) dual coding theory as the conceptual basis to understanding the difference in processing between visual and verbal information is useful. However, Marschark, Richman, Yuille and Hunt (1987) argue that the problem with earlier research is that is does not distinguish between how verbal and visual information are processed and stored, which Richardson (1999b p.124) refers to as the difference between 'dual coding and dual processing'. They postulate that high-imagery and low imagery materials differ in terms of the relational and distinctive processing that generally occurs at encoding, most notably in the verbal system. This means that how images are encoded depends upon its imaging qualities such as how easily it evokes an image. Taking this perspective a general assumption will be made that images and text can be processed differently and this is largely dependent upon their high and low imagery properties, without having to assume distinct memory systems.

One of the key issues is deciding what ranks as a high and low imagery representation. Paivio distinguishes between them on a more fundamental basis as *picture-like* and *language-like* dimensions (Paivio, 1986) which does not take into account their arbitrariness. The following table summarises the characteristics of his dimensions.

Table 4.1: Characteristics of Paivio's picture-like and language-like dimensions

Characteristics	***Picture-like***	***Language-like***
Artefacts	Photographs Drawings Maps Diagrams Graphs	Natural human languages Formal systems (Fregian) such as Mathematics Symbolic logic Computer languages
Properties	Analogue Iconic Continuous Referentially isomorphic (has links to other representations)	Non-analogue Non-iconic Digital or discrete (as opposed to continuous) Referentially arbitrary (does not have links to other representations) Propositional

While the picture-like and language-like dimensions correlate with an abstract-concrete description the correlation is not perfect. The two dimensions vary in abstractness both structurally and functionally (Paivio, 1986).

These distinctions have been the subject of some debate (Palmer, 1978; Shepard, 1978; Sloman, 1971). Sloman's work, although largely in the context of artificial intelligence, argues that differences between representations are scalar in nature and that this approach is a departure from the more general linguistic approach of representation. He recognises the difference between linguistic and non-linguistic information and that they need to be more effectively differentiated for use in artificial intelligence. Shepard argues that the differences in processing are characterised by analogical or logical thought in that analogue processing is where the internal states of the representation have a one-to-one relationship with the external world.

Palmer's (1978) view is that representations are characterised by their operational properties in that the information that can be derived from it is dependence upon the processes that can be performed on it. For example a representation could model the height of children in a class using a graph where the tallest line in the graph represented the tallest child. There is no need to specify the operation required in order to understand the information, as the mapping is intuitive. However, if the lines in the graph were used to represent hair colour, where the tallest line represented the darkest hair colouring, some augmentation would be required in order to facilitate an appropriate operation so that the correct information could be derived from it. This kind of mapping is not intuitive and needs augmentation (Preece, 1981; Scanlon, 1998). Palmer argues that it is this kind of distinction that differentiates and characterises representations.

Despite these minor differences, agreement centres on the mapping relationship between the form of the representation and the form of the represented world, and its degree of arbitrariness. Shepard's view of the analog-logic difference is very closely related to that of Paivio's picture-like and language-like distinction. Similarly Palmer's distinction based on the operational qualities of the representation are closely related to Paivio's distinction on the degree of arbitrariness with which a relationship maps onto the real world. Therefore the operational quality of the representation, i.e. its ability to support the process that enables appropriate information retrieval, is linked to the degree of abstractness of the coding mechanism of the representation. Conversely, language has almost a completely arbitrary mapping, and artificial languages, such as computer languages, have totally arbitrary mappings making them more abstract (Paivio, 1986). Thus operational quality is quite poor in such representations as it is more difficult to extract meaningful information that maps onto the real world. At this point it is useful to discuss ideas from semiological research.

Semiology is the science of sign systems; it studies languages, codes and signals in what is generally regarded as non-linguistic sign systems (Guiraud, 1975). The premise is that linguistic information and non-linguistic information are processed differently, in that the eye processes non-linguistic information and the ear processes linguistic information (Bertin, 1983). This perspective has obvious parallels with the dual processing perspective previous reviewed in this section.

Bertin defines auditory perception (that processes linguistic information) as having only two sensory variables, that of sound and time, and are linear and temporal in nature. Conversely non-linguistic perception has three sensory variables that do not involve time. These are the variation of marks and the two dimensions on a plane. The essential difference between these is that linguistic input is linear and only communicates a single sound or sign, while non-linguistic information is spatial and communicates relationships among three variables (Bertin, 1983, p3).

While linguistic information can be symbolic in nature and abstract, the interpretation is discrete, whereas non-linguistic representations have more dimensions that interplay, permitting ambiguity. This problem is compounded by what Bertin refers to as *seeing* and *reading* visual representations (Bertin, 1981). The value of visual representations is that they can easily be perceived, i.e., seen, by the visual processing system However this is eroded when a visual representation needs to be *read* as opposed to *perceived.* Visual representations requiring reading have to be processed by both systems increasing cognitive load.

There is an agreeable overlap between Bertin and Paivio in how information is processed, despite the fact they approach representation processing from different perspectives. Bertin and Paivio both agree that two separate coding units process information. Paivio's framework also encompasses ideas from the work of Guiraud (1975) whose *referential function* defines the ability to make referential links between the message and the object it links to, i.e., to make referential links between the representing world and the represented world. Paivio describes this as the *referential* level where one representation maps onto the image and visa versa.

Similarly Guiraud's *metalinguistic function* maps onto Paivio's *associative* level, where stimuli to either representation system will make associations within that system. Accordingly an abstract component in a visual representation will trigger another (more concrete and readily understood) associated representation in the visual system, or an abstract linguistic (word or concept) will trigger an associated (more readily understood) one in the verbal system. So there are links between semiology philosophy and dual processing. Semiologists philosophise about how things in the real world are represented (with strong emphasis on visual representations) and dual processing theorises on how representations are processed.

One of the fundamental problems identified within the cognitive psychology and semiology literature is the distinction between verbal and non-verbal information and their effects on processing. This is compounded by the comprehensibility of the representation and the arbitrary mapping between entities and real world objects. These representations are not transparent to novices. Even if there are more succinct ways of representing the information for experts, their value is not immediately apparent. In such cases, making the coding of the representation either transparent so the learner can understand the notation, or defining conventions that enable less ambiguous interpretation, can help to alleviate these problems.

Some multiple representations do not cue referential links and assimilation of information between representations is not realised (Scanlon, 1998). One way to achieve this is through an awareness of the coding mechanism of the representation and of introducing ways to augment this in a more formalised manner. The writer or teacher may assume that the interpretation is apparent, yet it may not be sufficiently apparent to enable novice interpretation in an efficient and succinct manner. This makes reference to other representations difficult.

Reading and writing expository representations are assumed to be transparent forms of communication, but the degree to which they are taught seems to be overlooked. They are the first forms of representation a child is taught in school and are used through school life. They include reading, writing, spelling and language construction. Even so students still have difficulty in extracting implicit ideas in text (Van Hout-Wolters & Schnotz, 1992). Other forms of representation such as graphs, diagrams, formulae, do not receive the same amount of intensive teaching in their construction and interpretation. It is reasonable then to assume that these too need interpretation instruction or additional augmentation, especially if they are abstract and contain unfamiliar notations inherent in complex information (Preece, 1981). Therefore the addition of a representation cannot be assumed to improve the effectiveness of an instructional text, regardless of how transparent its interpretation may appear to the writer or teacher.

The purpose of a representation needs to be clear to assess whether writers have achieved their aims of providing the most adequate representation to convey the information. This will then allow writers to identify whether any additional augmentation is required and what the best way is of doing this in order to assimilate information from all representations. A picture may well represent a thousand words but it is only useful if all the words are understood. The viability of a representation depends upon its ability to convey the same interpretation to all who encounter it (Petre, 1995).

To capitalise on a representation, associations need to be cued with previous representations such that an abstract relationship links with a more concrete real world representation. This enables a meaningful interpretation of an abstraction for the learner who is then in a position to capitalise on more succinct coding of information. As these links are not automatic they may need to be an explicit part of the representation to enable learners to fully understand them.

The prevailing distinction between representation types, from a cognitive perspective and within semiology, is the processing of high and low imagery information. Defining and deciding what ranks as either is crucial if explicit use is to be made of dual processing in an attempt to rationalise research on representation and to seek enhancements such as reducing cognitive load. Understanding how a representation maps onto the real world is a stumbling block, with some representations having overlap. For example, when a diagram becomes verbally littered with text, the perceiving element of a representation is swamped by reading activities. But how do we know when this has happened? The crux of the matter is *knowing when a representation is picture-like or language-like and how arbitrarily it maps onto the real world.* The answer would appear to be simple: it is picture-like when it looks like a picture and language-like when it looks like language. However, if a graph containing formulae is presented to students, it may add extra complexity as formulae themselves are abstract language-like representations requiring reading. In these circumstances the rationale that presenting a graph relieves the complexity of processing mathematical notation and expository text may be mistaken. The mix between text and visual representations will also have value when the visual representation and text are complementary (Hartley, 1994). This can only happen when the visual representation is intelligible to the reader.

While the cognitive issues explored in this section offer a theoretical basis for understanding how information is processed, they do not explain how to characterise a representation. Similarly Bertin and Guiraud's semiology research philosophises on representation but does not describe how to differentiate between representations. In order to provide a basis for comparing different studies, knowledge of the properties of representation and how they might be characterised is required. These themes are explored in the following section.

4.5 Properties of representations

This section reviews the properties of representations and how they might impact on learning. A number of dimensions are used by de Jong et al. (1998) to characterise representations. These are *perspective, precision, modality, specificity* and *complexity* and Rohr and Reimann (1998) add *ontology*. These are illustrated in Table 4.2.

Table 4.2 de Jong et al's Dimensions of Representation

Dimension	**Description**
Perspective	This is the view from which the information is perceived. i.e. a diagram might illustrate how organs in a human body behave in relation to each other, or it might show how an organ physical interacts with other organs. In this example the perspective is differentiated by behaviour and functioning.
Precision	This describes the level of accuracy by which an object is represented. For example a diagram might show a change in the volume of a container showing an increase or it might define discrete measures whereby the exact increase is know. The use of either may depend upon whether a qualitative or quantitative response is required.
Modality	This is used in the specific sense of denoting the form of expression such as text, diagrams, graphs, algebraic notations, formula and tables.
Specificity	This dimension relates to the computational property of a representation, i.e., the degree to which the coding of the representation supports the understanding of it. This is frequently used to describe diagrams. There are two approaches. The humanistic approach is where the computational properties are measured in terms of their correspondence to routine patterns of human reasoning. Typically all the information is close together and connected logically, reducing the need for symbolic searching. As they capitalise on perceptual inferences they are easy to read. However, departure from diagramming conventions can require augmentation or multilevel diagrams. Computation is the level to which conventions in the visual system need to be specified for interpretation. This relates to the ability of the coding system to express the information (Bertin, 1981; Jean, 1989; Stenning & Oberlander, 1995).
Complexity	This refers to the amount of information present. In multiple representation systems it can be used to indicate levels of redundancy. No redundancy is where each representation represents a different dimension Partial redundancy is where some of the information is available in the other representations Full redundancy where the same information is present in all representations.
Ontology	This refers to the content in terms of the objects and relations that represent a domain

As can be seen from Table 4.2 de Jong et al's dimensions are useful for differentiating between representations. However there are some shortcomings with these dimensions as tools for defining and using representations.

There are differences in how the *specificity* dimension is characterised. The computational properties approach is unclear and makes its usability as a dimension difficult. The computational approach to defining *specificity* is similar to the semiology approach of Bertin (1983), which offers more detail about how to specify a visual representation. Bertin (1981) provides useful information about how cartographers augment maps (in the form of legends) with relatively formalized procedures of coding that may be useful in other graphical representations where the inherent coding mechanism is unable to convey all the information contained in it. This information could usefully feed into clarifying this dimension.

The *complexity* dimension is vague and at present qualitative, for example, how much information qualifies as complex? Having any kind of metric for this is obviously difficult, as it may be representation dependent. For example, in expository representations it may be the number of concepts conveyed, where the level of complexity may be increased due to the style of the writing. In diagrams it may be the number of relationships being shown or the complexity between relationships. In graphs it may be the overlapping of data sets. In tables it may be the number of elements available for comparison, which may be difficult due to the complex nature of the information. However, the identification of redundancy among representations may be useful, not as a means to removing it but as a means to assess if, when, and at what level, redundancy between representations is useful. Wright (1982) concludes that writers often remove redundant information even though it can be helpful to readers.

The *precision* dimension does differentiate between qualitative and quantitative representations. Quantitative information is precise when actual values are used to illustrate changes in a state, whereas qualitative information is used to describe relationships. However van Joolingen (1995) argues that qualitative reasoning tends to be ambiguous and that quantitative precision needs to be complemented with qualitative information to capture all relevant aspects. Conversely, this may depend upon the type of information to be represented and its level of complexity. Nevertheless this distinction might provide useful information about situations where qualitative information, quantitative information or both are useful.

Unfortunately the *specificity*, *complexity* and *precision* dimensions require amplification to aid decision-making in the design and specification of representations. Co-ordination between multiple representations is required to enable predictions about when, where, and at what level augmentation is needed. However, de Jong et al's dimensions are useful for considering the adequacy of representation, particularly in the context of multiple representations.

Larkin and Simon (1987) distinguish between sentential representations and diagrammatic representations that are informationally equivalent, and, thus compare the efficiency of the two different representations. Their method of differentiating between representations is based on *informational and computational equivalence*: their ability to enable *information searching*, *recognising relevant information* and *draw appropriate inferences*. They note that the ease with which recognition occurs is strongly affected by what is explicit and what is implicit.

Larkin and Simon's approach has some parallels with Paivio's (1971; 1978; 1979; 1986) theories. "Two representations are informationally equivalent if all of the information in the one is also inferable from the other, and vice versa" (p676). "Two representations are computationally equivalent if they are informationally equivalent and, in addition, any inference that can be drawn easily and quickly from the information given explicitly in the one can also be drawn easily and quickly from the information given explicitly in the other, and vice versa" (p67). The searching within the representation requires an understanding of the coding system and associations between the coding system of the representation and information in memory. Understanding the representation is key to processing the information. Additionally, links need to be made at the *associative* level to facilitate searching of information. Learners need to have a transparent understanding at the *representational* level to interpret the representation unambiguously. They need to make *referential* links between representations to assimilate the information and also so they can relate to more transparent internal representations of information that are already known.

Larkin and Simon's (1987) view that the explicitness or implicitness of representation affects its efficiency, is similar to Paivio's (1986) view that a representation's abstractness is the degree to which it arbitrarily maps onto the real world. It would be expected then that a representation that has a more implicit meaning would be more abstract for learners. To understand a representation fully, learners would need to know the inferences that were implicitly expected in the representation notation.

Anderson (1984) takes a different view. He argues that the difference between representations is not embedded in the notation but in the operations that the representation supports. However, defining what operations a representation can support is difficult and such information does not inform how a representation is processed in order to support these operations. In any event, if the coding system of the representation system is transparent, then all the operations intended by the writer will be possible. The issue, then, is the transparency of the representation and not the operations that it supports.

The research reviewed in this section provides awareness into representational properties and some of the issues involved in distinguishing them. However, there are no tractable methods proffered that define representations or the degree to which they map onto the real world. The following section will consider how representations could be distinguished.

4.5.1 Differentiating between representations

A method is required in this thesis to distinguish between representations and their degree of abstraction to inform how they are processed. Research in multiple representations has had mixed results, and without theoretical underpinning explanations can be difficult to rationalise. For example, attempts to alleviate cognitive processing by providing complementary representations, (such as graphs), are reasonable pursuits. However, the *nature* of the graph may actually increase cognitive load, and researchers reviewing such results reported in the literature may conclude that *all* visual representations increase cognitive load. In other situations graphs might be helpful in reducing cognitive load.

At present, without the ability to distinguish between representation types and define abstraction within representation types, there is no way of intelligently comparing these results. Some method of distinguishing between visual and verbal information and their levels of abstraction could provide a basis for understanding levels of cognitive processing incurred by students. Additionally it would provide a foundation for comparing research results and for defining new studies based on understanding how representations are processed.

For the purposes of this thesis the proposed approach is to distinguish crudely between visual and verbal information. Visual information will be assumed to have spatial and relational qualities (Bertin, 1983; Winn & Holliday, 1982). Verbal information will be the converse, i.e. so what cannot be deemed to be a visual representation will be assumed to be verbal. Defining the degree of abstractness of a representation will be whether it maps onto the real world, i.e. its imagery quality (Richardson, 1999b). High-imagery representations are those that easily evoke a mental image of a visual representation that maps onto the real world. Low-imagery materials are those which present difficulty in stimulating mental images in the real world. While this appears to be a crude method for differentiating visual representations, Dondis (1973) argues against over-defining visual representational distinctions. He claims that unlike language, which can more easily be defined into different parts, visual representations can not easily be categorised and compartmentalised.

However there are a few problems with this approach in differentiating between representations. First it assumes an objective way of viewing a representation. As Richardson (1980; 1999b) points out in his work on mental imagery, the experience of seeing is essentially a private or subjective one. While there are behaviours that can be observed to indicate how an individual is feeling there is no similar observable behavioural characteristic than indicates what a person is imagining. Instead verbal communication is the only way that individuals can describe their internal images. The problem arises when all that view a visual representation do not perceive the same thing. Chamber and Reisberg's (1985) experiments on reinterpreting mental images illustrates that interpretations can be ambiguous.

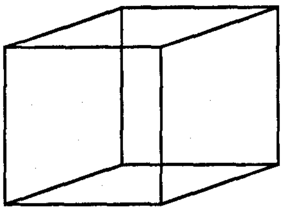


Figure 4.2 The Necker Cube

The Necker cube, illustrated in Figure 4.2 is a popular example used to show its two qualitatively different views (Prosser, 1993; Richardson, 1999a, 1999b; Thagard, 1996). The top edge can be seen as being either at the front or at the back of the cube. However, not all individuals will see the same perspective at the same time, reinforcing the view that perceiving the image is subjective and interpretive.

Visual representations can be interpreted in different ways. Thus describing them objectively is difficult as a large sample set would be required to investigate a best-fit generic view of what was being representing. However for the purposes of this thesis visual representations will be distinguished on the basis of high and low imagery to initially design the visual representations. These will be measured against participants' perspectives of what constitutes a visual representation. The following section discusses the implications of results from the literature in the light of cognitive processing issues and the method described in this section to characterise representations.

4.6 Implications

Understanding the effects of using multiple representations is complicated by apparent inconsistencies in results (de Jong et al., 1998). Scanlon's (1998) and Scanlon and O'Shea's (1988) work with novice physicists' showed that understanding an additional graphical representation proved difficult for students. Scanlon (1998) concluded that providing an additional representation can cause. cognitive overheads. She recommended that "Novices solving a physics problem can more easily achieve success when they restrict themselves to using only one representation of the problem" (p74). This may not generalise to other modalities, as the representation in question in this study was a graph.

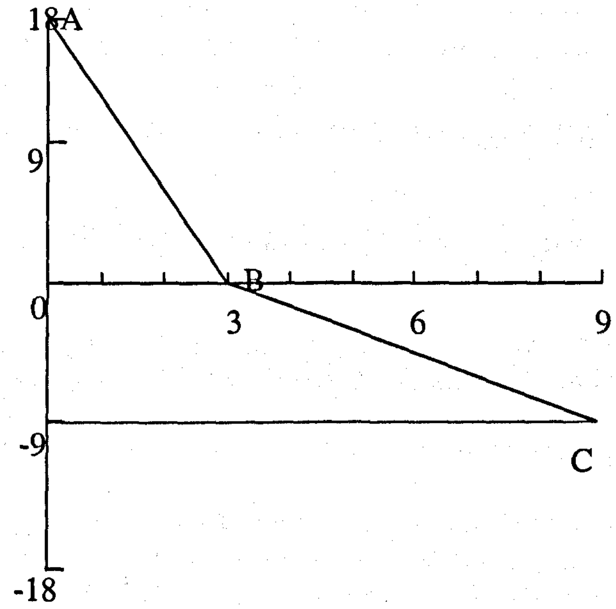


Figure 4.3 Scanlon's graph of velocity vs time for problem 2 (P75)

As Figure 4.3 shows this graph qualifies as a visual representation as it contains spatial and relational qualities. However, the representation is abstract with low-imagery properties as it would not easily evoke an internal mental image that relates to the real world. While this represents a shorthand notation for experts in the field, and one that students should eventually become familiar with, it may not alleviate learning difficulties for novice physicists as it is remote from the familiar concrete world.

These types of representations are therefore more likely to cause cognitive overheads rather than economies. Students, instead of learning from the representation, may grapple with the representation and its meaning. As Ainsworth et al. (1998) and Brna (2001) point out, there are overheads to using an unfamiliar representation as students need time to learn the coding system and understand its meaning. Bertin (1981) describes this type of representation as a *reading* graphic as it requires processing of symbolic information. The learner is required to process this information verbally as opposed to perceptually. Mousavi et al. (1995) refer to this as *split-attention*, where the verbal coding system is required to process input from more than one representation. As Scanlon (1998) points out, "Students found it very difficult to switch between the graphical representation and their mental image of the energy transformation involved in motion" (p75). As this representation requires some verbal processing and has low imagery qualities, it may explain why novices had difficulty linking a mental picture of the concrete application of motion to a largely abstract verbally coded one.

Tufte (1983) agrees that the most useful representations relate to life. Abstract representations challenge learners at two levels. It may cause split-attention requiring both representations to be processed unitarily thus inhibiting links between a concrete mental image and an abstract linguistic representation. Both representations may be informationally equivalent but not computationally equivalent. As Scanlon suggests, linking the two representations is not automatic and students may need some guidance in this, such as some explicit cues to enable referential links.

Conversely Mayer and colleagues (Mayer & Anderson, 1991; Mayer, 1989, 1997; Mayer & Gallini, 1990; Mayer & Sims, 1994) report success when using visual representations with novices in scientific domains. They compared three groups of novices who received *text with illustrations and labels*, *text with labels and no illustration*, or *text with illustration but no labels*. Scores on post-tests showed that the group receiving the illustrations with labels scored the highest, illustrating that labels on visual representations are important in aiding understanding. Mayer's (1989) illustrations in scientific texts can be considered as visual and concrete as they have spatial and relational properties that support high imagery qualities.

While the diagram without labels does have components that map onto real world objects, without the augmentation of the labels the components are still unknowns for the learners. The use of labels supports interpretation of the representation and provides cues to enable referential links between representations. While this labelling is useful it cannot be assumed to work in all cases as its lack of convention or codification could affect interpretation in other representations. However the use of such augmentation can cue referential links for novices using multiple representations that are informationally equivalent but computationally different.

Further evidence of this exists where the propositional representations are supported with visual high imagery representations (Mayer & Anderson, 1991, 1992; Mayer, 1997; Mayer & Gallini, 1990). These studies show that the labelling of diagrams enables referential links supporting assimilation of information evident in higher post-test scores, which they refer to as a contiguity effect. Their work strongly supports the theory that properties of representation and differences in processing can explain the effects of cognitive economies.

The lack of understanding of what constitutes a verbal and visual representation is evident in Brooks' (1967) early work in multiple representations. He claims that recall was enhanced if a complex message was presented in *auditory mode only* as opposed to *auditory and visual.* However the visual information he was referring to was text, which Bertin (1983) and Pavio (1986) argue is verbal information. This difference in Brook's representations is in the mode of presentation. As both these inputs would need to be processed by a verbal system then using two different modes to present the same information would overload the verbal processing system. This explains why using only one type of processing input enhanced message recall.

Mousavi et al. (1995) conducted a set of 6 experiments that examined the split-attention effect where students received information in a range of representations. This is based on cognitive load theory (e.g. Sweller, see Mousavi et al, 1995, for further reading).

> The split attention effect occurs when learners are required to divide their attention among and mentally integrate multiple sources of information. Mentally integrating multiple sources of information results in less effective acquisition of information than if learners are presented the same information in a physically integrated form. A physically integrated format reduces the load on working memory (p319).

Their research also encompasses Pavio's (1978; 1979) dual coding theory and Mayer's (1991; 1992) research on representation. In particular Mousavi et al.

identified that some combinations of multiple representations overload a coding system incurring *split-attention* where it has to process more that one representation, causing cognitive overload. However they differentiate between auditory and visual information in that auditory can be heard and visual incorporates reading tasks. Based on their experiments they argue that working memory is effectively expanded when mixed-mode representations can be processed in parallel, i.e., processed by the two separate coding systems.

While this thesis does not dispute the results *per se* it does challenge the underlying reasoning. Mousavi et al. did not differentiate between visual representations, such as diagrams and text, considering both to be processed visually. This contradicts Bertin and Paivio's view that text is processed by a verbal coding system. In Mousavi et al's experiments 1 to 4, where students were given *diagrams with text*, *diagrams with audio*, and *diagrams with audio and text*, they showed that time-on-task was faster when students received diagrams with audio. However the acquisition time was lower overall for diagrams with text where students worked at their own pace. Subsequently, the overall time spent, including acquisition and task solution, varied little between these two groups. However, both the *text with diagrams* and the *audio with diagrams* were processed by the same coding system but the modality of audio may be more effective for recall than reading. I.e., audio inputs may *force attention* while reading may *demand attention* as reading may be a more cognitively demanding task than listening (Mousavi et al., 1995).

However the 6th experiment in this series illustrated that an all auditory input was less effective than an *all-visual* version. The *all-visual* version, contained diagrams and text, was probably more effective as it supported a dual processing approach and cueing of referential links. The *all-auditory* version was processed only by the verbal system and did not support dual processing or enabling of referential links.

This thesis argues that the results of Mousavi et al's work show the effects of modality difference as well as the effects of split-attention in dual processing. This example illustrates that it is important to differentiate between representations in order to interpret results appropriately. Furthermore, cognitive processing of representations that are well understood can capitalise on the characteristics of dual processing, reducing the effects of split-attention and reducing cognitive load.

Understanding how to design instructional materials to capitalise on the affordance of different representations requires an understanding of their properties and how learners process them cognitively. Using multiple representations is desirable for a number of reasons.

First, providing multiple representations can provide a richer representation of concepts. It promotes more flexible knowledge acquisition helping to link as much information together as possible, both external and internal. In particular there is a growing body of cognitive psychology literature of visual instructional methods that promotes the potential of visually based representations for learning (Larkin & Simon, 1987; Mayer & Gallini, 1990; Waddill, McDaniel, & Einstein, 1988; Weidenmann, 1989).

Second, multiple representations can be used to fine-tune and refine knowledge, which Larkin and Simon (1987) argue is a qualitatively richer goal than knowledge acquisition.

Third, visual representations can show spatial relations more easily than expository text and promote intuitive and computationally effective perceptual inferences (Larkin & Simon, 1987). They can help relieve the abstraction and complexity of concepts.

Fourth, expertise is seen as the ability to switch readily between representations using the one most appropriate to the task. Using multiple representations is desirable in the progression from novice to expert (de Jong & Ferguson-Hessler, 1991).

Fifth, experts make use of imaginistic reasoning and can flexibly use different representations and translate quickly between them (Rohr & Reimann, 1998).

Using multiple representations does not improve performance in all cases as the reviews in this chapter of the research by Ainsworth, Green, Petre, Preece and Scanlon's has shown. However, there are good reasons to want to include them in instructional materials for students. These reasons, coupled with the abstract nature of computing, explain why visual representations are used in computing to relieve abstraction.

There are a number of particular specific conventions used in computing such as flowcharts, Jackson Structured Programming Design, Software visualisations, Unified Modelling Language diagrams and CASE tools. However, these are not always well codified and representations often borrow conventions from other sub-domains which are not well understood by novice programmers. Trying to provide generality may produce complex heuristic procedures; therefore specific problem domains may require more specialised types of representations, capable of providing richer forms more easily accessible by the user (Sloman, 1971). There are many examples of research into the use of visualisations to relieve abstraction in computing (Aczel et al., 1999; Ben-Ari & Kolikant, 1999; Brna et al., 2001; Cox, 1999; Du Boulay, Cox, Lutz, & Romero, 2001; Du Boulay et al., 1981; Exton & Kolling, 2000; Fung et al., 1993; Hendrix et al., 2000; Naps & Chan, 1999; Oberlander et al., 1999; Oliver, 1997; Pope, Kates, & Fineberg, 1983; Stenning et al., 1995; Stenning & Oberlander, 1995).

Oliver found that complementary representations were an effective way to support the reasoning process when using modal logic. Users developed a greater understanding of the key topics and greater skill in constructing proofs. Similarly, Aczel et al. and Fung et al. have investigated the use of visualisations in logic proof. Naps et al. found that students using computer animations were able to obtain a deeper understanding of an algorithm. Hendrix et al. found that using diagrams with expository text to explain control structures in the Java programming language provided measurable benefits in comprehension tasks. Ben Ari found the same when using diagrams to teach concurrency. Stenning, Cox and Oberlander have found that visual representations can help learners conceptualise. However their work focuses on external representations generated by the learner as external cognitive aids. There is enough research to illustrate that this is an area worthy of investigation.

To interpret the results of research into representations, an appreciation of the issues in cognitive processing and representational properties is desirable. This information should feed into the design of instructional materials for empirical research and the interpretation of results.

4.7 Conclusion

Given the nature of distance education and the abstract nature of computer science, it is reasonable to investigate representation as a way to optimise the learning environment for students. As computer science teachers strive to ameliorate learning difficulties in this complex domain it is natural for them to seek intuitive ways of relieving abstractions by using visual representations to complement expository text.

However, as this chapter illustrates, using representations is not straightforward. It is largely an instinctive vehicle used to try and relieve abstraction, not always successfully. Representation has a large part to play in how efficiently learners process information and whether it will increase or reduce cognitive overheads. Understanding how learners process representations requires an understanding of what and how they are processing. Paivio's (1971; 1978; 1979; 1986) framework was used to explain how learners process representations and to discuss split-attention effects (Mousavi et al., 1995) Bertin's (1981; 1983) semiologic research enabled interpretations to be made in this thesis of how representations are processed as either visual or verbal. Although critics of the dual coding approach argue either that all representations are stored propositionally or that separate but linked components process different forms of representation, the body of research supports the *dual processing* position.

The research that has been reviewed in this chapter found few tractable methods that differentiate between representations. In order to bridge this gap, different representations in this thesis are distinguished crudely as either verbal or non-verbal having high-imagery or low-imagery qualities. This serves as a basis for explaining variations in the literature.

The analysis of the research within this framework indicates that some results are due to split-attention where multiple representations present unitary processing. This is due in part to inappropriate distinctions between representations where visual representations require reading as opposed to perceiving, causing overloading of one system rather than more efficient parallel processing in two systems. Additionally, representations can be abstract so that learners have difficulty making referential links between representations and associative links within representations to similar (more concrete) previously processed representations.

Knowledge and understanding of the representational differences and inferences among cognitive processing and properties, can offer a framework within which to hypothesise about multiple representations and how they might be used effectively to reduce cognitive load for computing students at a distance. In developing instructional materials, visual representations are desirable as they afford quick and easy support to a large number of perceptual inferences. In computer science, they are frequently used as tools to relieve abstraction. Differentiating between representations and how they are processed should be a central component of reporting results in multiple-representation research in computer science. The literature reviewed in this chapter serves as a compass for directing the practical aspects of Study1 when examining representation preferences and their associated factors.

Chapter 5 Aims and Methods – Study 1

5.1 Introduction

This chapter describes the general aims of the research in this thesis and aims and methods in Study1. It provides an overview of the literature in chapters 3 and 4 that is salient to the research in the thesis and in particular to Study1. The thesis aim can be summarised as exploring the use of visual representations to ameliorate the problems in learning difficult concepts in computer science for students studying at a distance. The research in this thesis examines the influences of visual representations and cognition in learning, relating to individual differences in age, gender, and prior experience.

The chapter outlines the research in Study1 and its data requirements. The aim of Study1 is to establish the preferences and perceptions regarding representation in students and academics and compare and contrast those within the context of expert-novice differences. Additionally individual differences will be examined to assess their impact on preferences and perceptions. Other factors in the student group are considered such as incidental learning and background variables, including age, gender and prior experience. The representation choices made by academics are explored to examine best practice in designing instructional materials. The data requirements of this study are examined and the knowledge elicitation literature is reviewed to establish the most appropriate techniques for this research. The methods and materials used are reviewed in detail in order to select the most appropriate methods for the data collection required for Study1 (although one of the methods reviewed in this chapter, protocol analysis, is used later in Study2). The knowledge elicitation tools used in Study1 are card sorts, laddering and case analysis. Additional data are provided through individual difference tests, questionnaires and pre and post-tests. These support the data collection requirements of Study1.

5.2 Overview of the Literature in Chapters 3 and 4

The literature reviewed in chapter 3 and 4 illustrates the relevance of using both individual differences in learning and representation to improve instructional materials for distance education computing students. Investigating individual differences together with representation has similarly been explored other studies (Barratt, 1953; Bartlett, 1932; Cohen & Saslona, 1990; Hiscock, 1978; Paivio, 1971; Richardson, 1977a). These studies investigated the extent to which individual differences influence learning and the extent to which representational factors in instructional materials influenced learning. The evidence from chapters 3 and 4 similarly indicates that both approaches are worthy of investigation.

Investigating individual differences in learning and representation provides information from two perspectives. It allows judgements to be made about whether any enhancements in learning are due to improvements in representation or due to individual differences in human learning. In particular, research into both visual representations and individual differences in learning has been investigated by several researchers in teaching conceptually challenging areas in computing (Campagnoni & Ehrlich, 1989; Cox, 1999; Mayer & Sims, 1994; Stenning et al., 1995; Stenning & Oberlander, 1995).

Mayer (1991; 1992; 1989; 1997; 2000; 1990; 1994) has shown that the use of concrete high-imagery visual representations with expository text has been beneficial to learners. He interprets his results within dual processing theory (see Richardson (1980; 1999b), Paivio (1971; 1978; 1979; 1986), Kosslyn (1980; 1994; 1977), and Pylyshyn (1973)), and reports that students receiving information concurrently in a visual and verbal format are better able to build referential links and perform better in problem-solving activities (Mayer & Sims, 1994).

The dual processing theory, reviewed in chapter 4, on cognitive processing of representations, underpins Mayer's work in a number of ways. First the use of verbal and visual information enables learners to process complementary information. Visual information also exploits the perceptual quality of a representation that enables students to process spatial and relational information easily. Second, Mayer uses high-imagery concrete visual representations. As Richardson (1980; 1999b) and Paivio (1971; 1978; 1979; 1986) have pointed out, concrete representations have high imagery properties that enable learners to develop their own images supporting encoding in both verbal and visual systems. This means that recall can be from either coding system and increases the likelihood of it being remembered.

The prediction from the literature review is that text, supported by high imagery visual representations, has properties that should help students learn conceptually difficult areas. However, the review in chapter 4 illustrates that learning advantages may be due to particular learners' traits that prove advantageous when using particular representational types. Riding et al. (1989) and Riding and Douglas (1993) have shown that Verbalisers preferred textual materials while Imagers preferred non-textual modes. So any improvements in learning may not necessarily be due to representational design per se but may be related to individual differences in learning. Both representation and individual differences need to be investigated together to enable clear judgements to be made on the impact of improvements to representational materials.

5.3 Research Aims of Thesis

To examine whether any enhancements in learning are observed as a result of improvements in the representation of instructional materials or individual differences in learning, both representation and individual differences need to be examined. This thesis takes a student-centred practice-oriented approach to examining these issues.

The experimental methodology used examines preferences, perceptions, learning outcomes and learning processes of students. This investigates cause and effect relationships when students study different representations of instructional materials. As the approach adopted is student-centred, it is important to explore why particular cause and effect relationships might exist. This requires a largely qualitative approach that examines which particular treatments are more favourable in terms of preferences and learning.

Historically quantitative methods in psychology have been preferred to qualitative methods although more recently there has been a greater interest in using qualitative methods (Hartley, 1998; Richardson, 1996). Although this is not a thesis in psychology, it is concerned with learning, thus similar methodological considerations relating to the use of qualitative research also apply (Hartley, 1998). The difference between qualitative and quantitative research could be viewed as manifestations of two contrary research paradigms (Henwood, 1996). From this perspective, quantitative research is one approach that manipulates, measures, and specifies relationships between particular variables to test hypotheses about causal laws (p27).

Quantitative research has originated from scientific fields where experiments have been conducted in laboratory situations where conditions could be controlled (Woolgar, 1996). However humans are not inanimate materials that can be given treatments and observed in laboratories. Humans are complex and their interactions with the world involve complex processes. Thus quantitative research has a limited ability to examine human processing directly in natural situations or to provide explanation for human actions from an experiential perspective.

In contrast, qualitative research is based on understanding the meaning of the experience, actions and events as interpreted by particular participants and researchers, sensitive to the complexities of behaviour and meaning, as they typically or naturally occur (Henwood, 1996, p27). It enables the researcher to investigate the human experience of learning that is salient to individuals. It can explore the interconnection of terms, concepts and assumptions about human learning from an individual's perspective.

However qualitative research has its costs. The nature of this methodology demands small samples that researchers can sensibly test. Unfortunately this can sometimes be interpreted as having less precision and generalisability than quantitative research (Henwood, 1996). Additionally, qualitative research makes added demands on researchers. They need to be aware of

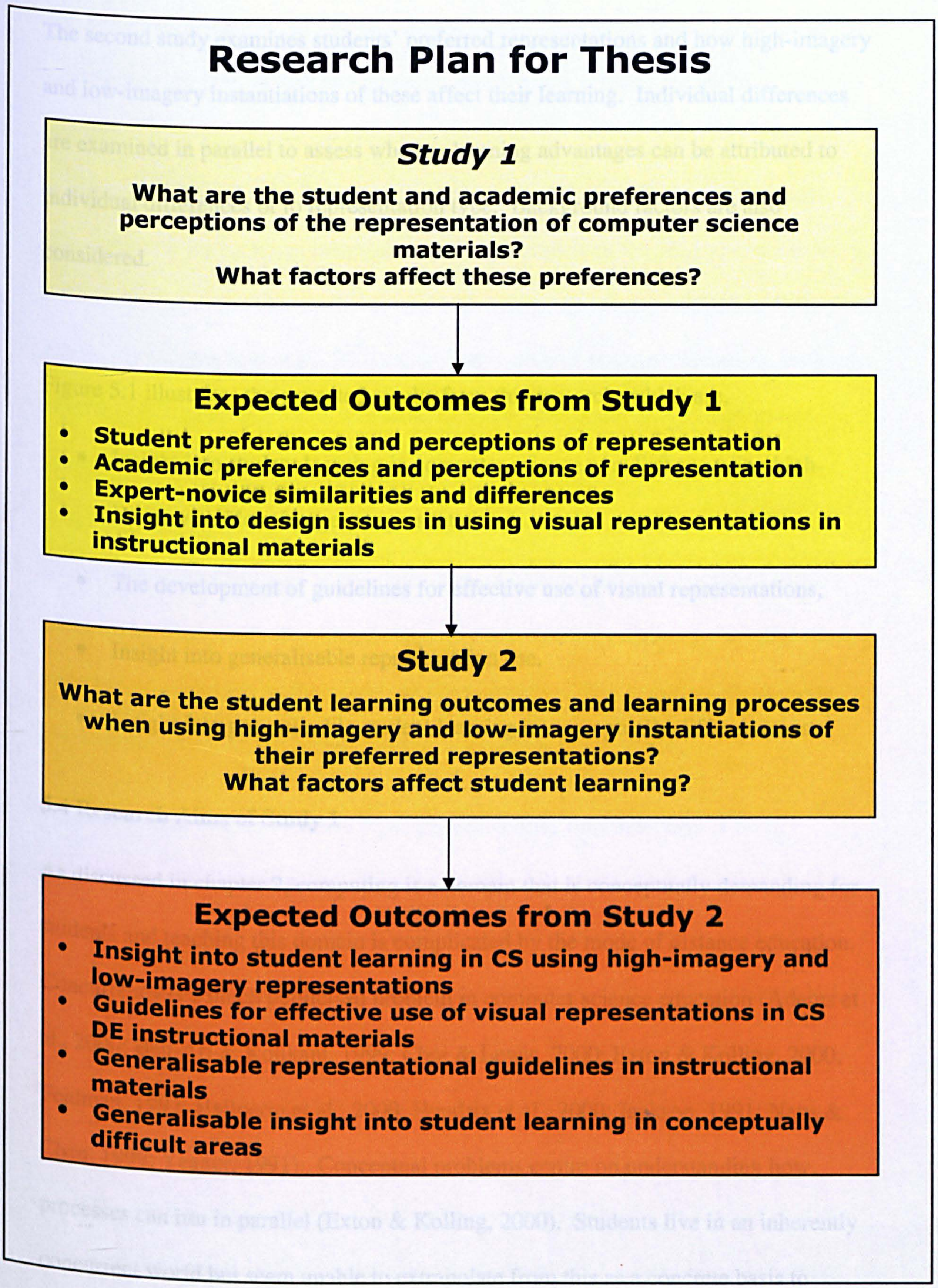
- the appropriate protocols for interacting with the participants
- how to make sense of the large amount of data collected (Richardson, 1996).

However, qualitative research is not 'a radical alternative to a dominant orthodoxy' nor a subversion based on fashion (Woolgar, 1996, p12). Neither is it of less value nor easier to conduct than quantitative research. It has had scientific utility in the social sciences and is an appropriate method of research in education.

Qualitative research need not exclude quantitative research: the two should be regarded as having complementary although possibly different roles in psychology research (Richardson, 1996), and this extends to research in human learning. Hartley (1998) suggests that a range of methods should be used in combination to address the advantages and disadvantages of different approaches. Adopting this philosophy this thesis takes a triangulation approach to examine the issues of using visual representations to improve instructional materials for computing students from a number of perspectives. The principle is that a more accurate result is likely (Smith, 1996, p189). It also enables researchers to get a richer or fuller narrative as well as strengthening the claims that they make (Smith, 1996). This thesis uses a range of approaches that explore qualitative issues and indicate quantitative trends.

Study 1 begins by establishing preferences and perceptions on representation. This is important, as providing students with representations that they do not prefer may be counterproductive, regardless of how effective they might be in experimental situations. Therefore the first study in the thesis will examine students' preferences in representation and whether they are related to individual differences or incidental learning. Academics' preferences and perceptions will also be elicited and compared with students' to examine expert-novice differences. Additionally background factors such as age, gender and prior experience will also be considered.

Figure 5.1 illustrates the plan of research and how Study1 feeds into Study 2.



Research Plan for Thesis

Study 1

What are the student and academic preferences and perceptions of the representation of computer science materials?
What factors affect these preferences?

Expected Outcomes from Study 1

- Student preferences and perceptions of representation
- Academic preferences and perceptions of representation
- Expert-novice similarities and differences
- Insight into design issues in using visual representations in instructional materials

Study 2

What are the student learning outcomes and learning processes when using high-imagery and low-imagery instantiations of their preferred representations?
What factors affect student learning?

Expected Outcomes from Study 2

- Insight into student learning in CS using high-imagery and low-imagery representations
- Guidelines for effective use of visual representations in CS DE instructional materials
- Generalisable representational guidelines in instructional materials
- Generalisable insight into student learning in conceptually difficult areas

Figure 5.1 Diagram illustrating the thesis research plan

The second study examines students' preferred representations and how high-imagery and low-imagery instantiations of these affect their learning. Individual differences are examined in parallel to assess whether learning advantages can be attributed to individual differences or to representation type. Background factors are also considered.

Figure 5.1 illustrates the expected results from this research, which are,

- Insight into student learning in computer science at a distance using high-imagery and low-imagery representations,
- The development of guidelines for effective use of visual representations,
- Insight into generalisable representation use,
- Insight into generalisable student learning in conceptually difficult areas.

5.4 Research Aims of Study 1

As discussed in chapter 2, computing is a domain that is conceptually demanding for students and teaching this domain is complicated by the mode of distance education. Concurrency is a much publicised problem in computer science education (Adams et al., 2000; Ben-Ari & Kolikant, 1999; Choi & Lewis, 2000; Exton & Kolling, 2000; Feldman, 1992; Hailperin et al., 2000; Hendrix et al., 2000; Jackson, 1991; Naps & Chan, 1999; Yeager, 1991). Conceptual problems centre on understanding how processes can run in parallel (Exton & Kolling, 2000). Students live in an inherently concurrent world but seem unable to extrapolate from this as a concrete basis to underpin theory (Ben-Ari & Kolikant, 1999).

The academic is required to find representations to teach conceptually difficult areas, such as concurrency, as well as representations that are suitable for use in instructional materials for distance education students. It is assumed that academics, as teachers, are experts in their domain and have knowledge of how to represent information in instructional materials to meet the criteria of teaching abstract topics in a distance education context. Yet reviews of computing courses within the Open University (McAndrew et al., 2001) and observations of popular computing textbooks (Bacon, 1998; Stallings, 1996; Tanenbaum, 1996) cast doubt on this assumption. Computer science teachers and textbook authors may not understand the effects of using different representations on student learning. Representations used by instructional designers may not be those that students either prefer or find helpful when learning conceptually difficult topics. This argument does not challenge the expertise of academics in their field but does challenge their expertise in designing instructional materials for teaching difficult concepts at a distance.

As discussed in chapter 4, visual representations offer intuitive ways of both representing and processing information. Additionally there is a growing body of literature that points to the potential of using visual representations in teaching scientific subjects (Mayer & Gallini, 1990; Waddill et al., 1988; Weidenmann, 1989; Winn & Holliday, 1982). Thus, this thesis explores the influence of visual representations and their effects on teaching a conceptually difficult area such as concurrency. The expectation was that students would prefer teaching materials containing visual representations, finding them intuitively easier to process, and that high-imagery (concrete) visual representations would offer cognitive advantages to students compared with low-imagery (abstract) visual representations when studying conceptually difficult areas such as concurrency.

The aim of Study 1 is to examine student and academic preferences and perspectives on representations to establish where they agreed and differed, examined as novice and expert differences. The triangulation approach is used to examine preferences for representation from a number of perspectives. Figure 5.2 illustrates the research plan for Study 1, showing the five types of data to be collected for students and academics. Three of these are the same for both groups of participants, but the last two are different. Data on incidental learning is required from the students and criteria for representation choice are required from the academics.

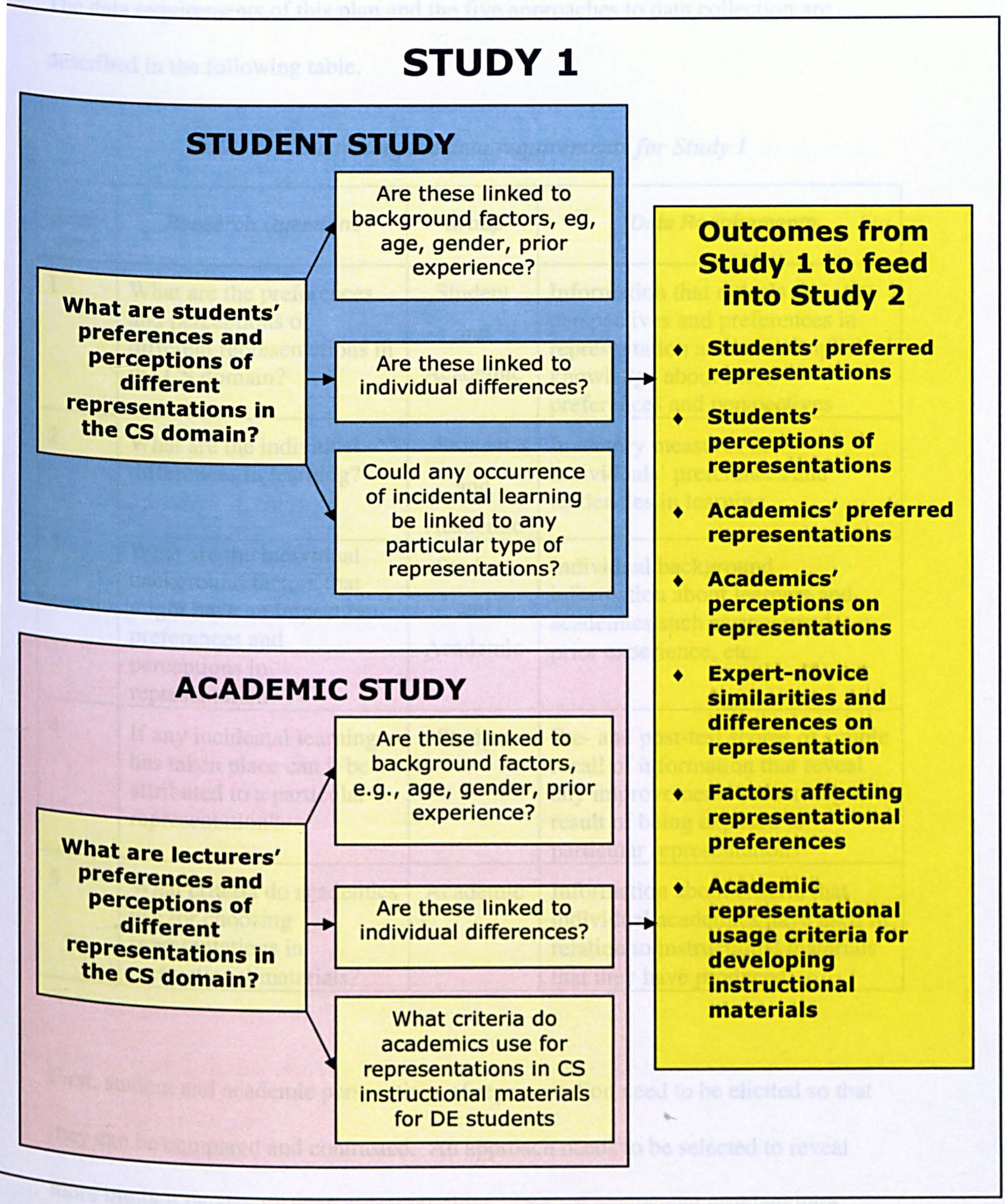


Figure 5.2 Model of research for Study 1

The data requirements of this plan and the five approaches to data collection are described in the following table.

Table 5.1 illustrating the data requirements for Study 1

Appr-oach	Research Questions	Group	Data Requirements
1	What are the preferences and perceptions of different representations in the CS domain?	Student and Academic	Information that reveals perspectives and preferences in representation and more implicit knowledge about these preferences and perspectives
2	What are the individual differences in learning?	Student and Academic	Inventory measures of individuals' preferences and tendencies in learning
3	What are the individual background factors that might have an impact on preferences and perceptions in representation?	Student and Academic	Individual background information about learners and academics such as age, gender, prior experience, etc.
4	If any incidental learning has taken place can it be attributed to a particular representation?	Student	Pre- and post-test scores of simple recall of information that reveal any improvements in learning as a result of being exposed to particular representations
5	What criteria do academics use for choosing representations in instructional materials?	Academic	Information about criteria that individual academics have used in relation to instructional materials that they have produced

First, student and academic perspectives of representation need to be elicited so that they can be compared and contrasted. An approach needs to be selected to reveal more implicit perspectives on representations. One acknowledged problem with using interviews is that participants are only able to access (and thus report) conscious as opposed to unconscious reconstructions of actions, as much human knowledge is difficult if not impossible to verbalise (Cordingley, 1989). What is needed here is a method that exposes perspectives that are less available to consciousness. This will be explored later in this chapter.

Second, individual differences in human learning need to be determined in order to assess whether they have an impact on preferences or perspectives. This has already been discussed at length in chapter 3. Three tests have already been identified for this purpose: the Group Embedded Figures Test, the Cognitive Styles Analysis test and the Learning Style Questionnaire. Administration of these techniques is described later in this chapter.

Third, background information, such as age, gender and prior experience needs to be collected. This is largely factual information and is easily collected by means of a background questionnaire. The administration of this is discussed later in this chapter.

Fourth, incidental learning and associations with any representation need to be monitored in students. This can be achieved by using pre and post-tests of simple recall from their exposure to the different representations of the instructional materials.

Fifth, criteria for choosing particular representations for information in developing instructional materials need to be collected from academics. This information needs to be elicited in discussion with academics, based around instructional materials they have already designed.

The first data collection approach requires information from students and academics on their preferences and perspectives on different representations. There are many different approaches to knowledge elicitation and a closer examination of the literature is required to establish the most appropriate. The following sections review the knowledge elicitation literature followed by a review of the techniques that are used in Study 1.

5.5 Knowledge Elicitation

Eliciting knowledge from individuals can be a challenging activity as there are no elegant methods of extracting the complete knowledge that an individual has (Welbank, 1983). Such information does not typically exist in any comprehensible generic codified form that is either easily articulated or externally represented (Buchanan, Sutherland, & Feigenbaum, 1969; Shadbolt & Burton, 1995). Describing this information in a generalisable form from which knowledge and problem solving can be identified is difficult (Shortliffe, 1976). The task of eliciting knowledge is enormous and considerable effort is spent on gathering, transcribing and analysing an individual's knowledge and is typically unsystematic (Shadbolt & Burton, 1995). Within the knowledge-based systems field this is known as the 'bottle-neck', characterising the problem of knowledge elicitation (Hayes-Roth, Waterman, & Lenat, 1983).

Shadbolt and Burton (1995) draw a distinction between natural and contrived methods illustrated in Table 5.2. Natural methods are those that individuals might naturally adopt when expressing or displaying their knowledge. These include techniques such as interviews, observations of actual problem solving and protocol analysis.

Table 5.2 Type of knowledge elicitation approaches and their techniques

Type	*Technique*
Natural	Interviews Case Analysis Focussed discussions Protocol Analysis Teachback
Contrived	Word Association Proximities Similarity Ratings Repertory grids Card sorts Laddering

Contrived methods are those that involve individuals performing contrived tasks that are not usually familiar to them. These include word association proximities, similarity ratings, repertory grids, card sorts and laddering. McGeorge and Rugg (1992) argue that contrived techniques take less time in transcription and coding. Natural methods come with attendant problems such as coding natural language and are susceptible to knowledge distortion when being coded by the researcher. In contrast, contrived techniques are expressed in a rigorous formalism from the start (McGeorge & Rugg, 1992, p151). The following sections review the most common natural and contrived knowledge elicitation techniques.

5.5.1 Interviews and case analysis

Interviewing is frequently used for knowledge elicitation. Interview data is useful for providing the researcher with background information and behaviour reasoning. It is a natural form of communication where an individual can correct the researcher's misconceptions in the data at the time it is collected. It can take the form of an unstructured contextual interview that is driven by the participant's interaction, or a structured facilitative interview where all participants are asked the same questions (Bell & Hardiman, 1989).

The main problem with interviews is that there is insufficient access to an individual's knowledge. Individuals can be unaware of the wealth of information that they have, or there may be poor communication between the interviewer and participant, making elicitation difficult. Even where these problems do not exist and participants are providing fluent information, it is often not as detailed as the interviewer would like. In particular experts often forget to articulate implicit relevant knowledge they assume to be explicit (Welbank, 1983). Additionally, analysing the results and comparing responses in interview data can be a difficult and a time-consuming procedure.

5.5.2 Case analysis

Structured interviews can be used to acquire detailed knowledge. One such approach is case analysis where individuals are asked to comment on how past cases were dealt with. This involves the participant reviewing previous work and in light of this describing the processes they went through to produce the work. This has the disadvantage of post-hoc rationalisation: processes and decisions are made in the light of more recent experiences and not based on the decisions made at the time the materials were created (Diaper, 1989; Tansley & Hayball, 1993).

However, this technique would be informative in uncovering the criteria used by academics in choosing representations for information in instructional materials development. This technique is suitable for use in Study 1 to discuss previous instructional materials academics have written and the rationale for their choices of representations.

5.5.3 Focussed discussions

Focussed discussions are elicitation techniques closely related to interviews. They are primarily used to elicits verbal protocols through discussion rather than performance on a task, which Cordingley (1989) characterises as an introspective rather than behaviourist approach. The distinguishing feature is that there is a third element introduced into the interaction that reduces its intensity. So instead of having the two elements of question and answer, the third element is the focus, where the discussion centres on an activity or an artefact. This is similar to the case analysis interviews described in the previous section. However one of the problems with focussed discussion is in encoding the verbal data (Ericsson & Simon, 1984), which can be a lengthy and complicated process.

5.5.4 Protocol Analysis

Protocol analysis can take a variety of forms and can be reported either concurrently (as the task or problem solving activity is happening) or retrospectively (after the task has been completed). One of the most common forms is concurrent reporting. This is a form of self-reporting that requires the individual to think aloud while performing the task, i.e. concurrently. As only individuals themselves have the ability to report on their own mental states and processes, gaining access to those through individuals' reports is the only way to gain knowledge of their processes. This form of analysis provides close inspection of how individuals perform processes in a way that other methods are unable to reveal (Tansley & Hayball, 1993). These provide simple reports of internal processes as they are happening, without elaboration or explanation (Gilhooly & Green, 1996). These verbal reports are then encoded into protocols that describe steps or actions in a process.

Retrospective reporting is another form of self-reporting. This is performed retrospectively after the task is completed and requires the individual to retrieve episodic memories of the process (Ericsson & Simon, 1984). Considerable accurate information can be retrieved from short-term memory if collected soon after the task is completed. It also has the advantage over concurrent reporting in that it does not interfere with the processing of the task itself (Richardson, 1998a). Richardson further argues that administrating post-learning questionnaires after the completion of a learning activity is an appropriate and valid means of obtaining retrospective reports (Richardson, 1998a, p611). Post-learning questionnaires are also reputed to have more accuracy than concurrent reports and have been shown to be accurately retained for up to a week later (Adams, Thorsheim, & McIntyre, 1969) (see Richardson, 1998a, for a full review).

Protocol analysis has the disadvantage of being a time consuming activity. Considerable time is required to plan the activity as well as analyse the data. Green and Gilhooly (1996) estimate that for each hour of data collected ten hours are required to analyse it. So while this is useful for gaining knowledge of individuals processes, it is time consuming to orchestrate.

While verbal protocols as a method of analysis have been criticised (McDaniel, 1988; Runquist & Farley, 1964), Ericsson and Simon (1984) argue that not only does this type of approach offer useful information but it can also be verified by other data (Richardson, 1998a). In their more recent edition Ericsson and Simon (1993) list a large collection of studies where protocol analysis has been used effectively and point out that this approach is now recognised as a major source of data on participants' cognitive processes in specific tasks.

5.5.5 Teachback

Johnson & Johnson's (1987) "teachback" can be used as an effective method for collecting new data (Cordingley, 1989). This is where the elicitor 'teaches' the participant some aspect of the knowledge that has been elicited. This technique can be included in an interview activity. Its value lies in putting the knowledge providers on the receiving end of the information, which allows them to supplement and clarify information. However, this produces qualitative data that can be difficult to codify. It is more typically used as a feedback and verification technique (Laurillard, 1978; Pask, 1976).

5.5.6 Word Association Proximities

This is a knowledge elicitation technique that requires participants to generate a list of words that they associate in response to a particular stimulus. For example, participants may be given the word 'disk' and asked to write down all the words that they associate with it. These lists of words are then compared between participants for their relatedness. The rationale is that words that are related in memory have a semantic proximity and are therefore more easily paired. They are retrieved from memory in related pairs. The word association task makes these connections explicit

(Jonassen et al., 1993). The task is useful for assessing the amount of structural knowledge a participant has.

There are two types of word association, free and controlled. Free association requires participants to write down as many words as they can associate with the stimulus within a specified time. The controlled word association requires the participant to rank each word in their list in order of the strength of the relationship to the target word, i.e., a word they association most strongly with the stimulus would be ranked as 1. This is slightly more error prone than the free association method.

Scoring for both procedures is complex, although a matrix of results can be drawn. From this data, relation coefficients (RC) can be calculated where high RCs indicate a greater overlap between words illustrating the degree of similarity in structural knowledge. However, there is a danger of a contiguity effect: terms may be recalled without having conceptual meaning with the stimulus as they were both present at the time of learning. As the data describes the semantic distances between concepts some irregularities may be missed as the analysis averages the data. Thus extreme ratings would be ignored (for a full review of this see Jonassen,1993).

5.5.7 Similarity Ratings

This process requires participants to rate the similarity between concepts on a scale. The method identifies categories of related concepts and the individuals' perception of how similar or dissimilar they are. The rationale for similarity rating is a spatial metaphor for depicting cognitive structure (Jonassen et al., 1993), i.e, how an individual perceives concepts and their inter-relationships with each other. The more closely related concepts are, the closer they will be together and visa versa. The ratings from a pair-wise similarity rating exercise (where the similarity of the pairs are rated) are typically represented as correlation coefficients in a half matrix. The most common method for analysing similarity ratings is to represent an individual's cognitive structure using multidimensional scaling (Fenker, 1975).

This method has largely been tried with university students. No validity or reliability ratings have been performed on different populations of learners, although similarity ratings show good reliability over time (Jonassen et al., 1993). This is a tedious process that is only useful for a limited set of concepts. For example a list of 15 concepts will result in 105 comparisons. Additionally the nature of the distance matrices analysis produces symmetric representations yet psychological processes are likely to be asymmetric (see Jonassen et al, 1993, for a full review).

5.5.8 Repertory grids

Repertory grids have been used to characterise domains of knowledge (Easterby-Smith, 1981). They are a way of exploring the structure and content of an individual's explicit theories and belief systems, which account for their individuality (Fransella & Bannister, 1977). These form what Kelly refers to as a personal construct system (Kelly, 1955). He postulated that humans perceive the world using patterns, i.e., they make sense of the world by categorising it. Kelly refers to these categorisations as constructs, which are abstractions of real world entities or events, enabling understanding and anticipation of events.

> Man looks at his world through transparent patterns or templates which he creates and then attempts to fit over the realities of which the world is composed. The fit is not always very good. Yet without such patterns the world appears to be such an undifferentiated homogeneity that man is unable to make any sense out of it. Even a poor fit is more helpful to him than nothing at all (Kelly, 1963, p9).

Kelly argued that it would be useful and convenient to examine personal construct systems as hierarchically linked sets of bipolar constructs. It is this bipolarity that makes the design of the grids possible. This allows the development of a matrix that he used to examine the pattern of interrelationships between constructs.

Repertory grids are highly attractive as knowledge elicitation techniques due to their amenability for sophisticated statistical analysis and their automated data entry via computers (Gaines & Shaw, 1997; Rugg & McGeorge, 1997; Shaw & Gaines, 1988; Winer & Vazquez-Abad, 1997). They also enable access to implicit knowledge (Tansley & Hayball, 1993).

However, the type of repertory grid used should be carefully matched to the types of domain knowledge as naïve application of the tools and the technique will generate spurious results (Rugg & Shadbolt, 1991). For example, if the knowledge domain consists entirely of continuous dimensions without discrete classes or absolute values, then either a rating or a ranking system would be appropriate. However, for dichotomous dimensions, a bipolar representation would be suitable. Repertory grids also become unmanageable with more than ten elements. In particular the grid is designed for a range of convenience rather than a range of inclusion. The validity of compelling individuals to record their knowledge in terms of bipolar constructs is debatable, as polarised constructs may not reflect their belief systems (Tansley & Hayball, 1993). This presents the researcher with elicitation design challenges in terms of the ranking, rating and bipolar allotment of constructs (Fransella & Bannister, 1977).

5.5.9 Card Sorts

Card sorting is a knowledge elicitation technique that is effective for eliciting mental categories and groups within these categories (Maiden & Hare, 1998). It can be used to identify concepts in a domain and how an individual organises them (Jonassen et al., 1993).

The technique is particularly useful in cases where participants may have difficulty articulating more implicit knowledge (Shadbolt & Burton, 1995). The technique works by giving participants a set of cards and asking them to sort them into different categories based on one criterion only. The criterion for the sort is the participant's own, thus reflecting their perception of artefacts. Participants can choose as many categories as they like for each sort including 'don't know'. The categories, cards and criteria in each sort are recorded. Participants are asked to keep performing the sorts (one at a time) until they can no longer find criteria for categories.

Cards sorts have been used informally for years but have received little attention in comparison with related techniques such as repertory grids and laddering (Major, 1991; Rugg, Corbridge, Major, Burton, & Shadbolt, 1992). The use of the card sorting method has a history of reliability and yet it is a novel and interesting tool to use. The technique has recently been formalised in a way that makes card sorting a credible and exciting method for qualitative and quantitative data collection and analysis. (See the card sort tutorial paper by Rugg & McGeorge, 1997, for a more detailed review).

The card sorting technique is a constructivist approach, aligned within Kelly's (1963) Personal Construct Theory (PCT) (Rugg & McGeorge, 1997). These constructs may be dichotomous categories or ranges. For example, a person may categorise two different shades of grey into two categories, where one is lighter than the other. These categories would be distinctions within a black-white construct. In the case of three different shades of grey, a person may choose to differentiate between them dichotomously, so that two shades will be grouped together into one category.

Alternatively the participant may choose to use a range of categories within this construct, so that they will be sorted into three categories, each representing degrees of blackness (or whiteness). The construct is an interpretation representing a personal conceptual distinction and may have similar overarching groupings used by many other individuals. Its advantage is that the original constructs and their groupings are unique to each person and have not been cued by the researcher, but still have enough similarity to enable comparison with other participants in a study.

Card sort data can be analysed by comparing and contrasting constructs, categories and cards within the categories. This can be done by using verbatim or gist agreement of constructs and categories within constructs (Upchurch, 1999). This process can be enhanced by using the laddering technique (which will be explained in the next section) to explore the definition of the participant's constructs, as labels may differ from the actual intended meaning of the construct and its criteria. Laddering offers a technique to explore the meaning of constructs in detail (Rugg et al., in press; Rugg &

McGeorge, 1995). The constructs can also be analysed to produce rules or multidimensional categories that enable identification of concept characteristics.

There are several advantages in using the card sort technique. It allows participants to state their own categories and groupings. They are not forced to respond to knowledge or structures that someone else has defined, so this form of knowledge elicitation is personal and salient to them. Card sorting is a well-structured task that can easily be comprehended by most participants (Jonassen et al., 1993) and is a simple technique to administer (Tansley & Hayball, 1993). Additionally it can illustrate relationships between constructs that the researcher may not have considered. It also overcomes the problem of recall of familiar but unmemorised information, that is, where the information has not specifically been memorised but gained through experience. Unmemorised information is difficult to recall even if it involves everyday occurrences (McDougall cited in (Welbank, 1983)). However card sorts offer a way to overcome this problem. Individuals' recognition is more complete than recall so offering participants artefacts to sort can provide more accurate recall of unmemorised information, particularly in context (Welbank, 1983).

Some of the disadvantages of card sorts are that the similarities and differences are limited to concepts presented in the domain and that the researcher needs a reasonable knowledge of the domain to interpret the data. However, card sorts can be used in any domain (Jonassen et al., 1993) and studies in a wide range of domains have produced rich data sets with interesting results (Chen & Occeña, 1999; Gerrard, 1996; Griffin, 2000; Maiden & Hare, 1998; Rugg et al., 1992; Upchurch, Rugg, & Kitchenham, 2001).

Maiden and Hare (1998) found that card sorting was useful for determining mental categories of problem domains to inform the design of semi-formal reusable objects in software engineering. They report that in relation to other knowledge elicitation techniques card sorts have the advantage of being quick and easy to use for both participants and researchers. This was an important factor in ensuring the participation of experienced software engineers in their study (Maiden & Hare, 1998, p287-288).

They found that card sorts were useful in providing additional knowledge that could be added to their system including extending dimensions, addition of applications, and additional enhancement to existing models. However they did note that knowledge elicitation took longer in the computing domain than in other domains such as archaeology. They argue that this could be due to domain characteristics: for instance, archaeology has known categorisations whereas software engineering does not, and therefore scoping categorisations takes longer.

Similarly, Upchurch (1999; 2001) used card sorts in the field of software engineering to develop metrics to evaluate web page design. One particular advantage was that important attributes would not have been identified if repertory grids had been chosen instead of card sorts. For example, Upchurch found that using card sorts enabled her to identify metrics for evaluation of web page quality where the greater proportion of these values were non-scalar. These would not have been possible if repertory grids had been used as the values obtained were nominal as opposed to numerical data categories. Thus the card sort technique was useful in highlighting the deficiencies of a numerical approach to evaluating web page quality. Card sorts proved a more comprehensive technique for this purpose. However Upchurch does point out that one of the weaknesses of card sorts is that the data is only at one level and attributes relating to classes, structures, and procedures would not be identified. She suggests that the laddering technique, as described by Maiden and Rugg (1996), would have been useful to decompose the attributes in order to operationalise the metrics used.

A similar study was conducted by Griffin (2000) who used cards sorts to investigate copyright infringement in web page design. Screen dumps of web pages were used as the cards and participants were required to sort these into categories. The number of times a card was categorised in the same group as another was used as an index to indicate its degree of similarity. The statistical analysis of the data indicated a high degree of commonality between plagiarised web pages.

Griffin also used repertory grids in this analysis and compared the two techniques. There was a high correlation of results between those constructs that were similar in both techniques illustrating reliability. However the card sort technique was rated highly by participants as easier to use. The participants also reported that the repertory grid technique not only took longer but also had constructs that they did not agree with and some of their own personal categorisations would not fit into the grid.

Gerrard (1996) used card sorts in a rather different domain. She found the technique useful in eliciting perceptions of working women's clothing. Not only did this reveal differences in perception between same gender and different gender clothing, but also that males consistently used dichotomous categorisations, which has far reaching implications for organisations, particularly in decision making. At present there is no explanation in the literature for this phenomenon.

In yet another domain Chen and Occeña (1999) used card sorts to elicit knowledge in the product design of golf clubs. The data was used to develop taxonomy trees to enable rules to be derived more effectively for product design. Chen and Occeña report that while this was only tested for product design it has potential as a knowledge elicitation tool for other domains.

This review indicates that card sorting is a useful technique for eliciting knowledge in a range of domains in a way that is user friendly and comprehensive. The data is easily collected and offers rich qualitative and quantitative data not readily available with the other techniques reviewed. The technique enables the researcher to investigate more implicit knowledge in a manageable way and can support the comparison of perspectives, both within groups and between groups of participants, (as is required in Study 1 between students and academics). This technique is suitable for use in Study 1 to elicit preferences on different representations used in instructional materials with students and academics.

5.5.10 Laddering

Card sorting can be supported by laddering to define constructs and categories. Laddering is a technique that has a long history in a wide range of disciplines as a useful knowledge elicitation technique (Rugg & McGeorge, 1995). Laddering also has its roots in Kelly's (1955) Personal Construct Theory and was originally developed by Hinkle (1965) as a method of clarifying the relations between constructs elicited in repertory grids. Within the knowledge elicitation context, laddering operates as a structured questioning strategy (Corbridge, Rugg, Major, Shadbolt, &

Burton, 1994). It models knowledge as a set of hierarchies and these can be goals, tasks or explanations (Rugg et al., in press, p3).

The technique uses a ‘seed’ (starting item) from which to expand the hierarchy by going into more detail or to discover more overarching categories to which the seed belongs. This is performed using a set of probes (questions) to elicit knowledge that reflects the structure of the constructs already identified. During this process the researcher must follow a repertoire of questions to ensure that hierarchies and explanations are equitable for comparison. This provides qualitative information in the form of a two-dimensional graph, where the nodes are connected by labels and definitions (Shadbolt & Burton, 1995). This technique can be used as a complementary procedure to card sorting, as the technique can be used to elicit knowledge to explain or further define constructs (Corbridge et al., 1994).

Rugg et al. (in press) have used laddering to elicit information about organisational culture. This proved useful in investigating attitudes towards new technologies. In another domain Wallis and Nelson (1997) found laddering useful in linguistics. Here, laddering was used to process tree structures in the development of natural language processing systems.

Burton et al. (1988) also found laddering useful in eliciting information. They compared the technique with protocol analysis, interviewing and card sorting for eliciting knowledge of the geographical features of glaciers. A knowledge base had already been developed and the information elicited was compared against this for coverage. Laddering proved to be the most effective technique in terms of efficiency and coverage.

Corbridge et al. (1994) have used laddering to elicit knowledge both in metallic corrosion and in medical diagnosis. When compared with the card sort technique, they elicited over three times the number of clauses, although the laddering technique did take longer than the card sort technique. Their experiments also showed that no practice is required for these techniques to be effective. In addition laddering was a high productivity technique that elicited twice as much as that achieved by other natural techniques such as interviewing and self-reporting. However they suggest that laddering is less suitable for early acquisition of knowledge and works best when the data from card sorts or repertory grids are used as input.

This review illustrates that the laddering technique has been used in a wide range of domains and has been shown to be effective in terms of coverage of information and efficiency. It is also reported to be complementary to other techniques such as repertory grids and card sorts. This could be used with the card sorting technique in the following way.

For example, if a participant has defined a construct as 'like' during the card sort procedure then the laddering process would start with this construct and the researcher could ask the participant to define 'like'. The researcher would continue probing 'down' the ladder asking the participant to explain each of the terms they mention until very detailed information is reached and the participant is unable to provide further information. The following is an example of this process and what it looks like on paper. (Appendix D also illustrates how constructs are expanded using probes from the researcher).

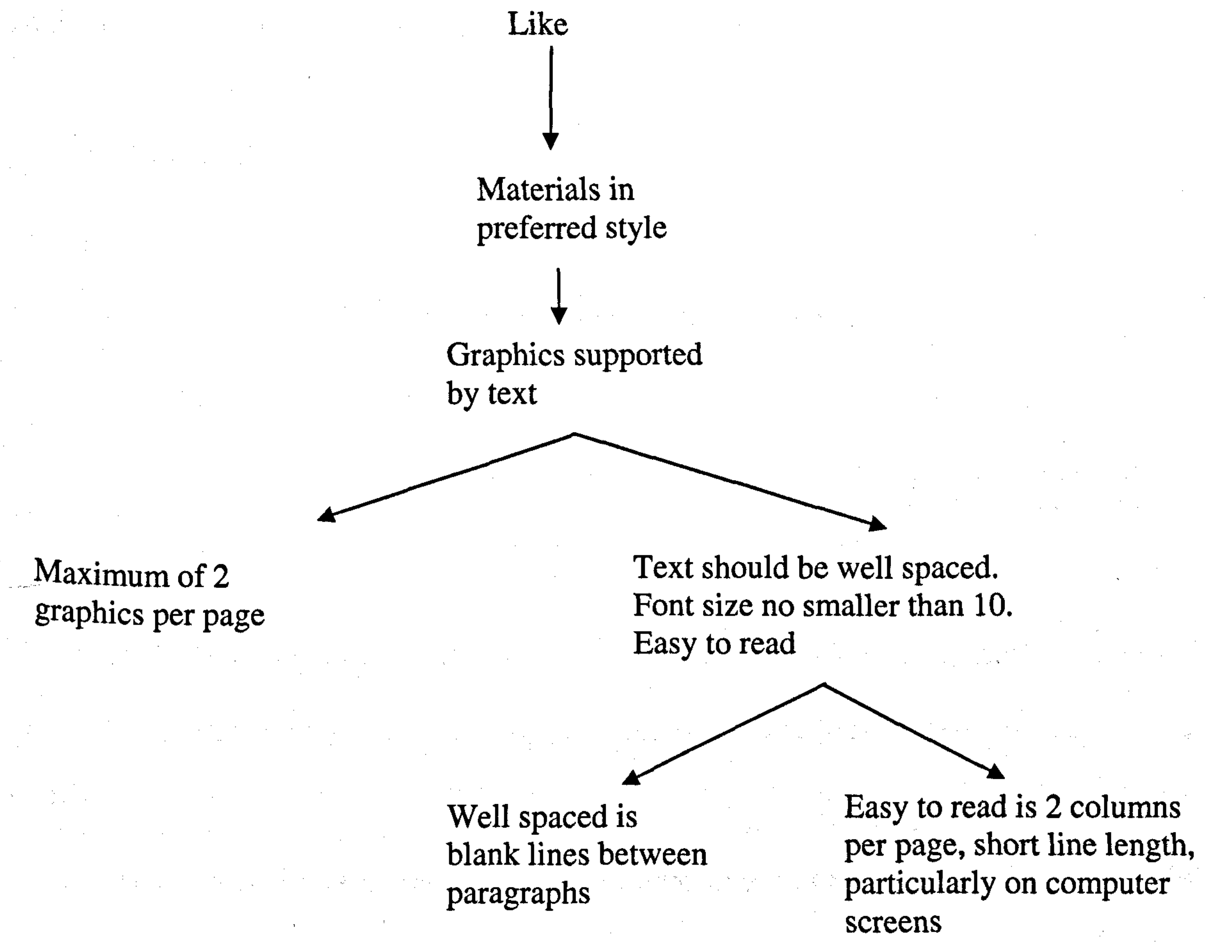


Figure 5.3 Diagram illustrating the laddering techniques used to define constructs

From the laddering process in Figure 5.3 the construct 'like' has been defined to mean a document that has text and graphics, with 2 graphics per page maximum. The text should be in two columns with short line lengths and blank lines between paragraphs. The font size should be no more than point 10. This illustrates the depth of information that can be achieved using this technique.

This technique would be used after the card sorting session to get a participant to explain constructs that they have defined or further explain less apparent categories they have chosen. In some cases participants may be able to provide discrete values within their category. Thus this technique is suitable in Study 1 for complementing the card sort technique to provide richer information about the meaning of the participants' constructs and categorisations.

5.6 Methods Used in Study 1

The methods used in Study 1 are similar to those employed by Sadler-Smith and Riding (1997) where they investigated the relationship between cognitive style and instructional preference. However Study 1 differs in that it uses card sorts and laddering as knowledge elicitation techniques to uncover unconscious preferences and categories as opposed to a self-reporting inventory of preferences.

Burton et al. (1988) used cards sorts and laddering with individual difference tests for introversion/extraversion and field independence, to examine performance of participants using different knowledge elicitation techniques. They found that cards sorts and laddering were valuable and reliable approaches to knowledge elicitation, especially when compared with interviewing and protocol analysis. Protocol analysis was found to be the weakest approach in examining implicit knowledge and the most time consuming. Card sort and laddering were found to be more efficient and at least as reliable as interviewing, with laddering proving to be richer. Both techniques together provide efficient and informative data.

There are two advantages in using the contrived techniques of card sorts and laddering, as opposed to natural techniques for investigating preferences and perspectives on representation. First, learners are not reporting what they *think* their preferences are: by using these approaches they are revealing what their *actual* preferences are. Second, this method is what Laurillard (1978) refers to as an educational technology approach, where research is practice-oriented, as students preferences will be elicited on educational materials similar to those used in a learning situation.

All of the methods chosen in this study have been driven by the type of data required to answer the questions posed in Study 1. Table 5.3 illustrates the research questions, the data requirements of questions and the techniques that support these. The purpose of the table is to illustrate how the methods chosen have been focussed on the data requirements of the research questions.

Table 5.3 illustrating the research questions, data requirements, and data collection techniques used in Study 1

Research Questions	***Group***	***Data Requirements***	***Data Collection Technique***
What are the preferences and perceptions of different representations in the CS domain?	Student and Academic	Information that reveals perspectives and preferences in representation and more subconscious information as to what constitutes these preferences and perspectives	• Card Sorts • Laddering
What are the individual differences in learning?	Student and Academic	Individual learner traits on preferences and tendencies in approaches to learning	• Group Embedded Figures Test • Cognitive Styles Analysis Test • Learning Styles Questionnaire
What are the individual background factors that might impact on preferences and perceptions in representation?	Student and Academic	Individual background information about learners and academics such as age, gender, prior experience, etc?	• Background Questionnaire for students • Background Questionnaire for academics
If any incidental learning has taken place can it be attributed to a particular representation?	Student	Pre- and post-test scores of simple recall of information that reveal any improvements in learning as a result of being exposed to particular representations	• Pre-test of concepts covered in card sort activity • Post-test of concepts covered in card sort activity
What criteria do academics use for choosing representations in instructional materials?	Academic	Information about criteria that individual academics have used in relation to instructional materials they have produced	• Case analysis interview

Table 5.3 illustrates the range of techniques used in Study 1. The range of methods can facilitate a deep analysis of the issues of representation using a breadth of techniques. This affords rich qualitative data that can also indicate quantitative trends. These combinations will however constrain the number of participants that can sensibly be tested in this study, particularly if they are going to be compared with academic participants. Therefore it was decided to use 12 students and 12 academics, gender balanced in this study, i.e. 6 males and 6 females in both groups.

The following sections will review the details and administration of these techniques used in Study 1.

5.6.1 The Card Sort Method

Card sort materials most commonly take the form of cards or pages that have entities on them with numbers written in the top corner of each to uniquely identify them. However, they are not restricted to this form, and objects and pictures have also been used (Rugg & McGeorge, 1997). The minimum number of entities for sorting is eight and the maximum (to easily manage) is thirty. All items should be of the same size and form, unless that is a feature of the knowledge to be elicited. (A full description of the technique is available in Rugg and McGeorge's, 1997, tutorial paper).

The terminology used in card sorts is personal construct theory based. It is described here to provide clarity in explaining the method (Kelly, 1963; Rugg & McGeorge, 1997).

A **construct** is an attribute that the participant uses to describe a category. For example 'easy to read' or 'amount of information'.

A **criterion** is the attribute that is used as the basis of the sort and is used to decide what categories to put items into. For example, readability might be a criterion used in the construct 'easy to read', and similarly 'volume of information' might be a criterion in the construct 'amount of information'.

A **category** is a group that participants class items into. There maybe be two, three, four or more groupings. For example, in the 'easy to read' construct there may be two categories 'easy' and 'hard'.

Participants are given a set of instructions (see Appendix A) which is reviewed with them. They are then given cards to sort which display items that they are asked to sort into categories. They are asked not to use the number of the card as a means of sorting and to use one criterion at a time for the sort. The names of the categories, the card numbers in each category, and the criteria for the sort are all recorded on a sheet. (An example of the card sort recording sheet is provided in Appendix B).

Participants are asked to repeat this activity until they can perform no more sorts. The card numbers are clearly recorded separated by a comma to avoid confusion during data analysis. Additionally cards recorded in each sort are counted to ensure all have been recorded. After each sort it is important to assess whether the participant has used only one criterion. If it is obvious that this has not been done then participants are asked to repeat the sort using only one criterion.

A large flat space is recommended (Rugg & McGeorge, 1997); however, because the cards used in this study are A4 pages, participants may choose to use a large clear floor area, so that they can initially look at all the items and then arrange them. Additionally sessions are recorded on tape for reference.

5.6.1.1 The Card Sort Materials for Study 1

The card sorts contained 16 separate 'cards', which were actually single A4 sheets of paper with a piece of learning material on them. In total 4 topics were covered: *Compilers, Concurrency, Entity relationship modelling*, and *Data Types*. While concurrency was the topic chosen as an example of a conceptually difficult area in computing, different topics were chosen so that choice of representation was not linked to a particular topic. Based on experience two difficult topics were chosen, Compilers and Concurrency, and two easy topics were chosen, Entity Relationship Modelling and Data Types. For each topic there were 4 different representations:

- all text, which contained only text
- structured text, which included text with either tables, numbered points, or bulleted points
- mixed representation, which included text with either tables, numbered points, bulleted points, and a visual component (diagram)
- visual representation, which contained text and one or more visual representations (diagrams).

Each card was randomly numbered so as to ensure that the numbers were not used as a criterion for sorting (Maiden & Hare, 1998) and to enable the researcher to identify cards for data recording. An overview has been included here in Table 5.4 to illustrate the types of representations used over the four topics.

Table 5.4: illustrating card numbers and their representation type for each topic

	Compilers	***Concurrency***	***Entity-Relationship Modelling***	***Data Types***
All Text	1	14	16	3
Structured Text	9	6	15	10
Text with Visual (diagram) components	13	2	11	8
Mixed: Text, Structured Text and Visual (diagram) components	5	7	12	4

Each box in the table indicates the number of the card. For example card 1 is an all text representation of the compiler topic, while card 12 is a mixed representation of the entity-relationship modelling topic. See Appendix C for the full set of materials used in the card sort activity.

Each of the representations used in the card sort materials contained examples (or worked examples), which reflected the style of the representation. Each representation was standardised on the following criteria to avoid confounds:

- All representations were as pure as possible. Other than the mixed representations, each representation contained only that type (See Table 5.4).
- All representations within a single topic were as factually similar as possible, i.e. there was **no difference in the level of the content** within a topic. The same information was used in each of the 4 representations, but different parts were chosen to be represented in different formats.
- For each representation within a topic there were a few subtle differences, such as example types, key words and phrases termed **nuggets.** These **nuggets**

were used to trace whether any episode of incidental learning was linked to a particular representation.

The presentation of each document had the same format. That is, the same font size, margin size, paper type, and heading style was used in all cards, using Hartley (1994; 1995) for guidance in the instructional design.

5.6.2 The Laddering Method

Participants' constructs were used as the seed for the laddering procedure. The laddering activity was performed after the card sort session. The probing questions were used to get participants to define their construct. Within this definition participants were then asked to explain terms and definitions that they had introduced. This procedure continued until there were no obvious levels of hierarchy or explanation left as participants had defined very specific attributes, or when participants found further articulation difficult. These were recorded on a blank sheet where the participant's details were recorded and enough space was available to draw the hierarchies (see Appendix D for an example of the sheet and the data recorded).

5.6.3 Individual Differences Tests

The individual differences tests were used in both studies. In Study 1 they were used to assess their value in predicting preference for representation. The particular instruments used were the Groups Embedded Figures Test (Witkin et al., 1971), Cognitive Style Analysis (Riding, 1998), and Learning Style Questionnaire (Honey & Mumford, 1992).

5.6.3.1 The Group Embedded Figures Test

The Group Embedded Figures Test (GEFT) (Witkin et al., 1971) was used to measure the cognitive control of field independence. It assesses a participant's preference for structure in representation. Participants were given a booklet and were required to draw around a simple figure embedded in a more complex figure. The test consists of three sections each with standard times allowed for completion.

Section One - This section comprises 7 questions. The participants were given 2 minutes to complete this section.

Section Two - This section comprises 9 questions. The participants were given 5 minutes to complete this section.

Section Three - This section comprises 9 questions. The participants were given 5 minutes to complete this section.

Section one contains very simple items and is for practice only. Sections two and three are progressively more difficult than section one. The manual (Witkin et al., 1971) contains a scoring key and participants score one mark for each figure correctly identified. There are eighteen marks in total, nine for each of the two sections marked.

Participants were given this test before the main activity in each study.

5.6.3.2 Cognitive Style Analysis

Cognitive style is perceived as a preferred habitual approach to organising and representing information on two principal cognitive dimensions: Wholist-Analytic and Verbal-Imagery (Rayner & Riding, 1997; Riding & Rayner, 1997). It is used in this study to examine preference for visual versus verbal information. The CSA test was administered before the main activity in each study. It is computerised and was run on a portable personal computer. The program prompts participants for their name and age, and then gives some simple instructions. Participants were then asked to press a key marked with a red sticker as a correct answer and a key marked with a blue sticker as wrong.

There are two parts to the test. The first asks participants to agree or disagree to a range of statements. The second part illustrates a complex figure and a simple figure where participants have to agree or disagree that the simple figure is contained in the complex one. The test is automatically scored, and the information is saved into a text file. On completion of the test, participants were given their cognitive style and were provided with a paper interpretation of this style (provided in the CSA pack). Additionally the data was recorded on file and contained the participant's name, age, Wholist-Analytic Ratio, Verbal-Imagery Ratio, WA speed index, VI speed index, WA correct (percentages of correct answers) and VI correct (percentages of correct answers).

5.6.3.3 Learning Style Questionnaire

The Learning Style Questionnaire measures orientations on four learning dimensions: *Activist, Reflector, Theorist,* and *Pragmatist.* The LSQ has 80 statements, 20 for each of the four learning styles. The statements are not weighted; each is ticked for agreement or crossed for disagreement. Within-style scores indicate the strength for each preference. Each student's profile is a *composite* of the four ratings; the questionnaire indicates an overall profile, not a rigid type designation. The test is easy to use and quick to complete. It takes approximately 10-15 minutes to complete and about 5 minutes to score (see Appendix E for an example of the questionnaire).

Participants were asked to complete this questionnaire before coming to the experiment in both studies.

5.6.4 Background Questionnaire

The background questionnaires were designed to collect additional information about students and academics. These were similar to questionnaires used by Bayman and Mayer (1988). This included information in the following categories.

Table 5.5: Sections in Background Questionnaire

Section	***Type of Information***
Age & Gender	Age and gender of participants
Prior Experience	Experience in computing both as a user and developer
Prior Knowledge	Theoretical knowledge. In particular what experience they have had with the topics used in the card sort activity.
Education and Employment	What their educational background was and what type of occupation(s) they have worked in.
Study Materials: *Students only*	What kind of printed representation they prefer and which they find the most useful.
Attitudes	This section focused on their attitudes to computers, representations of simple real world situation e.g. a map or instructions as direction to a location, and self reporting characteristics

The background questionnaire differed only slightly between lecturers and students. The prior experience question in the lecturer questionnaire was directed at what they had taught, and in the student questionnaire it was directed at what they had studied (for an example of both questionnaires see Appendix F).

5.6.5 Pre-test and Post-test (Incidental Learning)

The purpose of the pre and post-test was to examine whether students had learned anything *incidentally* while engaging with the instructional materials in the knowledge elicitation exercise. The goal was to assess whether incidental learning was related to any particular representation type. The pre-test was a sub-set of the post-test and was designed to ensure no cueing of representation type took place. (These sessions were recorded on audiocassette). Both tests contained simple recall questions on each topic where they were asked to remember facts as opposed to applying knowledge. The post-test however gave students an opportunity to provide an example (in any representation of their choosing) to illustrate their understanding. See Appendix G for examples.

5.6.6 Case Analysis of Academic Representation Criteria in Instructional Materials

Case analysis was used with academics to gain knowledge of their criteria in using different representations in developing instructional materials. Academics were asked to bring to the session an example of some teaching materials they had written. The purpose of this was to review the types of representations they had used in their materials and explore the kinds of issues and decision making during this process, aiming at establishing best practice. In particular academics were asked when and why they had used visual representations and how they had decided on appropriateness. This took the form of direct questions on the materials that were not covered in any of the other techniques. This activity was performed after the laddering activity.

5.7 Piloting the Materials

The card sort materials and the laddering technique were piloted with a group of students in the University of Northampton, under the supervision of Gordon Rugg who is an established authority on this methodology. Both the card sort materials and the laddering technique were deemed to be acceptable and no changes were made to the card sort materials. The full set of materials for study 1 were piloted with two academic participants and two student participants all of whom were on campus at the Open University. Again the materials for the card sorts and the techniques proved to be acceptable and no changes were made. However some minor changes were made to the background questionnaire based on the comments from the participants. These are listed below.

In question 2 the terms used on the Likert scale were changed from '*rarely*' (with a value of 1) to '*never*' and from '*often*' (with a value of 5) to '*everyday*'. The YES/NO part of this question was also changed from '*Is this related to your job*?' to '*Do you use this for your work?*'

In question 6 the wording was changed from '*What programming languages have you used and for how long?*' to '*Have you studied/used programming languages? If Yes, please complete the following table*'.

In questions 7, 8, 9, and 10 a '*Yes/No*' box was added after the question.

In question 15 the wording was changed from '*Have you any comments about the M206 materials in terms of how they helped you learn*' to '*If you have any comments about the M206 materials, in terms of how they helped you learn, please include them here*'.

5.8 Summary

This chapter describes the research aims in this thesis and the aims, methods and materials used in Study 1. The thesis focuses on the influences of visual representations and their cognitive advantage in ameliorating the learning of difficult concepts in computing while studying at a distance. It also considers the usefulness of individual difference tests in examining learning in practice-oriented research.

The aims of Study 1 are to elicit student and academic preferences and perspectives on different representations to establish the influence of visual representations. It was expected that students would prefer *visual representations with text* compared *with all text* materials. Both groups were required to participate in a knowledge elicitation exercise that examined student and academic preferences and perceptions of visual representations in order to compare and contrast novice-expert differences.

The knowledge elicitation literature was reviewed to assess the most appropriate method of facilitating the data requirements of this study. Cards sorts and laddering were tools identified as capable of supporting the knowledge elicitation data requirements in this study.

Student tests for incidental learning were aimed at establishing whether any links existed with representation type and these included pre and post-tests. Academic case analysis interviews on representational choices they had made during the development of their instructional materials, were aimed at providing information about best practice in representational use.

Individual differences were measured to assess their impact on preferences and perceptions in representations. The instruments used were the Group Embedded

Figures Test (Witkin et al., 1971) for field independence, Cognitive Styles Analysis (Riding, 1998) for Verbaliser/Imager and Wholist/Analyst, and the Learning Styles Questionnaire (Honey & Mumford, 1992) to assess learning style. Additionally background questionnaires were collected to provide information that might offer other accounts for preference and perspective in representation and performance on post-tests.

The range of interesting and diverse methods used in this research was chosen to support the triangulation approach in this thesis. They also facilitate the data requirements of the research questions in Study 1 (although one of the methods reviewed in this chapter, protocol analysis, is later used in Study 2). The approach uses a variety of qualitative techniques coupled with some quantitative techniques to provide information about preferences and perspectives in representations. These techniques constrained the sample size to 12 students and 12 academics although the approach will provide rich qualitative data that can indicate quantitative trends.

The approaches used in this study are aimed at meeting the overall goal of this thesis: understanding the influences and cognitive advantages of using visual representations to ameliorate the difficulty of learning conceptually challenging concepts at a distance for computing students.

Chapter 6 Study 1: Examining Participants' Preferences and Perceptions of Visual Representations

6.1 Introduction

This chapter describes Study 1, which examines the preferences and perceptions of distance education computing students for visual representations and compares these with academic perspectives. It was predicted that students would prefer visual representations as they would perceive them as easier to process. It was also predicted that there would be differences between students and academics in their preferences and perspectives on representation.

To investigate novice-expert differences between students and academics, knowledge was elicited from both groups on representation. Participants were required to exhaustively sort 16 items, spanning four different topics and four different types of representations. The knowledge elicitation tools used were card sorting and laddering. Student post-tests were used to establish whether any incidental learning was related to exposure to particular representations. Further, to provide information about representational design issues, academics participated in case analysis interviews on instructional materials that they had previously written. The individual difference instruments of the Group Embedded Figures Test, Cognitive Style Analysis, and the Learning Style Questionnaire, were used in this study to confirm their value in predicting preference for representation.

The results show that using visual representations in instructional materials can cue students into perceiving them as easier to read and understand, even when different representations of materials are informationally equivalent. Comparisons between students and academics indicated a gap in preferences and perceptions between the two groups, but not one that reflected expected novice-expert differences. Academics did not reveal themselves to be reflective practitioners, having insight into their own representational design choices. However, useful information was gleaned from the laddering activity in both groups to provide guidelines in representing instructional materials for this domain and mode of learning. The study illustrates students' strong preferences for instructional materials containing visual components and that academics lack awareness of the appropriate use of representation in instructional materials to facilitate learning computer science at a distance.

6.2 Method

6.2.1 Participants

There were 24 participants in Study 1. They were two groups consisting of 12 students and 12 academics and containing 6 males and 6 females.

Students at the Open University are spread over 13 regions in the United Kingdom and Ireland, with some students also being in Continental Western Europe. As the research required both researcher and participant to meet face-to-face for the study, the selection had to be restricted to regions that were within a day's travel of the university. This extended to locations that were within a 60-mile radius. This approach to sampling Open University students was similarly adopted by Di Paolo (2001).

The students were volunteers who were studying an Open University introductory computing course. There were approximately 4000 students studying this course and an email was sent to students in regions within a 60-mile radius to ask for volunteers. Participants were then selected on a first-come first-selected basis. The students were provided with an honorarium of £10 for participating.

The academics were lecturers in the computing department of the Open University, and were experienced in writing distance education materials for computer science students. The academic group was also made up of volunteers. This included most of the women in the computing department and a complementary quota of men to balance the sample.

Table 6.1 Gender and age balance of the participants

		Age Group					
		Under 24	**25-29**	**30-39**	**40-49**	**50-59**	**60-64**
Students	Female	0	2	2	2	0	0
	Male	3	0	2	0	1	0
	Total	**3**	**2**	**4**	**2**	**1**	**0**
Academic	Female	0	0	2	3	1	0
	Male	0	0	1	2	2	1
	Total	**0**	**0**	**3**	**5**	**3**	**1**

The student group and academic group had comparable ages ranges as can be seen from Table 6.1. However there is a slight difference between groups in the balance of ages. The student group had younger students than the academic group. In particular there are no academics under the age of 30. It is likely that this represents a general trend in universities as there are few teaching academics under the age of 24. Overall the academic group is slightly older than the student group.

6.2.2 Design

All participants received the same instruments except for 2 items:-

1. The pre-test and post-test were given to students only, as they were used to establish whether any incidental learning had occurred.

2. Only the academics participated in the case analysis interviews. These were based on instructional materials they had written.

The background questionnaire differed only slightly for the academics and students. In the academic questionnaire, prior experience was related to teaching experience and in the student questionnaire it was directed at what they had studied.

Participants were all tested individually. The instruments, as described in chapter 5, were administered to each group in the following sequence:

6.2.2.1 Student Group

Table 6.2 Instruments used in Study of Students

Instrument	***Procedure***	***Time Limit***
Background Questionnaire	Completed before study in participant's own time	None (10 mins to complete)
Learning Style Questionnaire	Completed before the study	(10 mins to complete)
Group Embedded Figures Test (GEFT) for Field Independence	Administer in study	12 minutes
Cognitive Styles Analysis (CSA) testing for Verbal-Imagery, Wholist-Analytic	Administer in study	None. Computer program records the time and calculates results (10 mins complete)
Pre-test	Administer in study	None (10 mins complete)
Card Sorts	Administer in study	1 hour
Post-test	Administer in study	None (10 mins complete)
Laddering Interview	Administer in study	None (30 mins complete)

The maximum time taken for the students to complete all components of the study was approximately 2 ½ hours. However most participants took around 2 hours with some taking a little less time. The time variations were in the card sort activity and the laddering activity, which were dependent upon the students' levels of contribution.

6.2.2.2 Academic group

Table 6.3 Instruments used in Study of Academics

Instrument	*Procedure*	*Time Limit*
Background Questionnaire	Completed before study	(10 mins complete)
Learning Style Questionnaire	Completed before study	(10 mins complete)
Group Embedded Figures Test (GEFT) for Field Independence	Administer in study	12 minutes
Cognitive Styles Factor referenced tests (CSA) testing for Verbal-Imagery, Wholist-Analytic	Administer in study	None. Computer program records the time and calculates results (10 mins complete)
Card Sorts	Administer in study	1 hour
Laddering Interview	Administer in study	None (30 mins complete)
Case Analysis Interview on instructional materials academics had written.	Not time specific	Not time dependent (30 mins complete)

The maximum time taken for the academics to complete all components of the study was approximately 2 ¾ hours. However most participants took around 2 ½ hours with some taking a little less. The time variations were in the card sort activity, the laddering activity and the case analysis interviews, which were dependent upon how much academics contributed.

To minimise any effects of practice, boredom, or fatigue over time by the researcher, the participants in the study were counter balanced in multiples of four. Each group of four contained one male and one female academic and one male and female student. As far as possible each set of four was tested on the same day.

6.3 Results

6.3.1 What is the overall preference for instructional materials in both groups?

At the end of the card sort activity each participant was asked to choose the learning material they preferred most in each topic area. All 24 participants were asked to choose their preferred cards in each of the four topics. Two academics said they could not make this kind of judgement and that they would need to read them all in-depth before deciding. One lecturer said he could only make a choice on three topics, as he didn't like any of the representations in the Concurrency topic. Table 6.4 illustrates the choices for representation type in both groups.

Table 6.4 Preference for Representation

Representation type	**Students**		**Academics**	
	N	%	N	%
Graphical	22	**46**	14	**36**
Mixed	21	**44**	14	**36**
Structured	5	**10**	9	**23**
Text only	0	**0**	2	**5**
Total	N=48	**100**	N=39 (missing=9)	**100** **(excluding missing values)**

In this table N represents the number of preferences

As can be seen from Table 6.4 there is a strong preference for materials that contain visual components. The student group had 90% (46% visual with text and 44% visual with text and structured text) of their choices for materials containing visual representations, compared with 72% (36% visual with text and 36% visual with text and structured text) of academic choices. In total, 70 choices across both groups i.e. 80% were in favour of learning materials containing some form of visual representation,. Hence students really liked instructional materials that contained visual representations. Academics also liked materials with visual representations, but not quite as much as the student group.

The null hypothesis was that participants will have a 1 in 4 chance of selecting any particular representation at random, i.e. 25% of choices will be attributed to random selection.

Table 6.5 Comparing actual selection with probable selection of representation for students and academics

Representation type	**Students**		**Academics**	
	preferences	**Comparison with probable selection of 25%**	**preferences**	**Comparison with probable selection of 25%**
Graphical	**46 %**	**+ 21%**	**36%**	**+ 11%**
Mixed	**44%**	**+ 19%**	**36%**	**+ 11%**
Structured	**10%**	**- 15%**	**23%**	**- 2%**
Text only	**0%**	**- 25%**	**5%**	**- 20%**
Total	**100 % (N=48)**		**100 % (N=39)**	

Table 6.5 illustrates a comparison of the percentage of students and academics that chose particular representations and the probability that the choice was due to a random effect (i.e. the figure represents how much greater or lesser the value is than the expected value of 25%). The table provides evidence to reject the null hypothesis that selection of representation is at random and is indicative of the strength of preferences by each group. In particular students are almost twice as likely to choose a representation that contains a visual component (i.e., either visual or mixed) as would be due to random selection.

To consider whether choice of representation has any relationship with topic, choices were grouped by topic for academics and students.

Table 6.6 Preference for Representation by Topic

	ER		Compiler		Concurrency		Data types		% Total	
	S	A	S	A	S	A	S	A	S	A
Graphical	50%	70%	67%	50%	58%	11%	8%	10%	**46%**	**36%**
Mixed	50%	20 %	17%	30%	42%	66%	66%	30%	**44%**	**36%**
Structured Text		10%	17%	20%		11%	25%	50%	**10%**	**23%**
Text						11%		10%	**0%**	**5%**

S = Students, A = Academics

Table 6.6 illustrates the preferences for representation by topic for students (S) and academics (A) in percentages. Interestingly academics made a greater choice for a wholly graphical representation in the Entity-Relationship (E-R) modelling topic, although 10% still prefer a more textual representation. E-R modelling is largely represented in graphical notation and as experts in the domain, academics are probably aware that this is the most pragmatic form of representing. Conversely at least 50% of academics prefer more textual representations to convey information about data types. This could be explained by academics having enough experience to develop their own internal models of data structures and therefore only requiring a textual description for explanation (Hanisch, Kramer, & Hulin, 1991; Petre, 1990).

However, as these measures are not independent, i.e. there are up to 4 measures per person, there could exist an interdependence. For example, if participants choose a mixed representation on one topic they might also choose a mixed representation on another topic. Chi-square was used to examine whether any interdependence existed between the preferences in representation and topic (see Appendix H for details of full results). Obviously, any study that involves small sample sizes will be subject to a reduction in statistical power (i.e., an increase in the Type II error rate). Consequently, one needs to be cautious about interpreting nonsignificant results. A separate point is that it has often been claimed that the chi-square test is invalid if some of the cells have small expected values because this may affect the Type I error rate. In fact, both analytic studies and Monte Carlo simulations have demonstrated that the chi-square test is highly robust even with total samples as small as 20. Consequently, one need not be any less confident about interpreting those results that *do* achieve statistical significance (Richardson, 1994).

Table 6.7 Chi-Square values for interdependence between choice of representation and topic

Topics	χ^2	**d.f.**	***p***
Entity Relationship and Compiler	1.10	4	0.894
Entity Relationship and Concurrency	3.02	6	0.806
Entity Relationship and Data Types	2.68	6	0.848
Compiler and Concurrency	6.16	6	0.405
Compiler and Data Types	8.21	6	0.223
Concurrency and Data Types	4.98	9	0.852

Table 6.7 illustrates that there is no evidence to suggest that the choice of representation in any topic was dependent on the choice in another topic.

One concern was whether the information on the cards within each topic was considered to be informationally equivalent by the participants. The results revealed this to be the case: 12 students (i.e. 100%) and 11 academics (i.e. 92%) sorted the cards by topic as defined in Table 5.4 on page 124. This confirms that the cards were not only designed to be informationally equivalent within topic but were also perceived to be informationally equivalent by the participants in this study.

Participants were given a score for prior knowledge based on their information from the background questionnaire to enable tests for association. For each of the four topics a maximum of 5 could be awarded, with a maximum of 20 overall (see appendix K for details of the scoring of the questionnaire). Preference for a visual (graphical) representation was given 4, a mixed representation was given 3, a structured representation was awarded 2, and an all text choice was awarded 1. These were then totalled. Thus a participant that chose a visual representation in all four topics would score 16. This was to construct a variable, even if only on a nominal scale, that reflected the degree of preference for visual representations. This was then used to test for associations with prior knowledge.

The scores for prior knowledge were correlated with the scores on preference for visual representations: There was no relationship found in the student group between preference for visual representation and prior knowledge (Spearman's rho=-0.97, n=12, p=.763). However in the academic group a negative correlation was found between these two scores (Spearman's rho= -.663, n=10, p<0.05). This indicates that academics that have more experience with the topic have less preference for materials with visual components.

However, similar tests between prior educational attainment and preference for instructional materials showed no relationship. Age and gender were examined as part of the background data to determine whether there were additional factors affecting results. An inspection of age and gender indicated that there was little relationship between preference for instructional materials and these factors.

6.3.2 What are the general judgements being made by both groups?

The data from the card sort activity was prepared into a table that listed all the constructs from all the participants alphabetically. An independent judge was asked to categorise these into superordinate constructs for a more global comparison within and between the groups. This data was analysed in a similar way to work by Griffin (2000), Sanghera (2001), and Upchurch (1999; 2001).

The categories, with definitions derived from the laddering activity, are in the following table, Table 6.8, illustrating the frequency of students' and academics' constructs in each superordinate construct.

Table 6.8 Frequency of student and academic constructs within superordinate constructs

Superordinate construct Definition		*Academic Constructs*			*Student Constructs*			*Total number for construct*
Construct	*Laddering definition*	*n*	*% of total constructs*	*% of academic constructs*	*n*	*% of total constructs*	*% of student constructs*	
Accessibility	How inviting the documents look, how interesting they would be.	**10**	43	12	**13**	57	16	23
Appropriate level for 1st reading	How appropriate it is for the reader depending on their level of experience with the topic	**6**	67	7	**3**	33	4	9
Level of difficulty	How difficult it is, if it looks complicated	**2**	29	2.5	**5**	71	6	7
Representation style	Whether text, graphics, bullet points, diagrams, code etc are used to represent the information.	**22**	55	27	**18**	45	23	40
Content	What the sheets contain.	**17**	45	20	**21**	55	27	38
Pedagogic Style	Whether they use Questions & Answers, overview or factual information, simple or complex, what is used to motivate students	**19**	70	23	**8**	30	10	27
Typography	Use of fonts, use of bold, shading	**2**	67	2.5	**1**	33	1	3
Volume	Volume of information, amount on page, words per page	**5**	33	6	**10**	67	13	15
Total per group		**83**		100 %	**79**		100 %	162

As a group, students are most concerned about content (27%) followed by representation style (23%) and accessibility (16%). Comparatively the academic group is most concerned about representation (27%) followed by pedagogic style (23%) and then content (20%). Within constructs, academics are slightly more concerned about representation style than students (55% academics, 45% students). This trend is reversed in the content construct with students being slightly more concerned about content than representation (55% students, 45% academics). Academics were at least twice as concerned as the students were about the teaching method (70% academics, 30% students). This trend is reversed in the volume construct with students twice as concerned about this as academics (students 67%, academics 33%).

Overall academics are most concerned about representation and slightly less so about pedagogy while the students are more concerned about content followed closely by representation.

6.3.3 How are the groups viewing visual representations?

The superordinate constructs only provide a global perspective. Therefore to examine more closely how students and academics are categorising cards in relation to visual representations, constructs within the superordinate constructs were examined for patterns. Clusters were identified for constructs by two independent judges, in a similar way to research performed by Sanghera (2001) and Upchurch (1999; 2001). The clusters were Visual-Text, Like-Dislike, Easy-Hard, Introductory-Deeper Reading, and Not Dense-Dense and were grouped together with verbatim or gist agreement. Table 6.9 shows these constructs and which superordinate construct they belong to.

Table 6.9 the superordinate construct and the corresponding cluster of constructs with verbatim and gist agreement

Superordinate Construct	**Construct indicating clusters of agreements**
Representation Style	Visual-Text
Accessibility	Like-Dislike
Level of Difficulty	Easy-hard
Introductory	Introductory-Deeper Reading
Volume	Not Dense-Dense

Frequency tables summarise these constructs for both students and academics to compare views between groups (for a more detailed look at the actual constructs and the card numbers see Appendix H). The student perspectives are reported first.

6.3.3.1 Students' perception of visual representations

Table 6.10 shows the frequencies for cards in the commonly identified constructs Visual-Text, Like-Dislike, Easy-Hard, Introductory-Deeper Reading, and Not Dense-Dense. These were tabulated by factor (i.e., feature) against attribute (i.e., construct) the analysis performed is similar to Chen and Occeña's (1999) in their research using card sorts.

As the constructs tabulated in Table 6.10 are the students' own constructs not all students identified cards within these particular constructs, which is why some cards such as card 9 do not appear to be classified as either text or visual. When card 9 is scrutinised the reason becomes clear: it has a rather ugly table that uses shading in such a way that might cause categorisation dilemmas for participants. This card appears in 'don't know' or 'not applicable' categories that students also used, not shown here.

Table 6.10 Student frequencies for constructs

Card	Description	Visual	Text	Like	Dislike	Easy	Hard	Intro-ductory	Deeper	Not dense	Dense
1	Text: Compilers	0	9	1	9	0	4	2	2	1	5
2	Visual: Concurrency	10	0	5	2	3	0	1	1	5	1
3	All Text: Data Types	0	8	0	9	0	4	1	2	0	8
4	Mixed: Data Types	7	1	7	1	2	0	1	1	2	3
5	Mixed:: Compilers	7	0	4	0	2	0	5	0	8	0
6	Structured Text: Concurrency	0	6	1	6	2	1	3	2	0	5
7	Mixed: Concurrency	8	0	5	0	2	0	4	0	0	4
8	Visual: Data Types	6	0	1	2	1	0	4	1	0	6
9	Structured Text: Compilers	0	0	1	2	1	1	0	0	1	7
10	Structured Text: Data Types	0	0	3	0	1	0	2	0	0	1
11	Visual: E-R Modelling	9	0	7	0	3	0	3	0	1	3
12	Mixed: E-R Modelling	5	1	6	0	4	0	4	0	0	2
13	Visual: Compilers	10	0	8	1	3	1	3	1	5	0
14	All Text: Concurrency	0	8	1	8	0	3	2	1	1	6
15	Structured Text: E-R Modelling	1	1	1	1	2	0	1	0	0	2
16	All Text: E-R Modelling	0	9	1	9	1	2	4	2	0	6
Total		63	43	52	50	27	16	40	13	24	59

Students' identification of text and visual representations as seen in Table 6.10 corresponded with those defined in the study, with both seen as distinctly different. There were only 2 students who differed from this. One student identified card 15 as text, while the other identified card 15 as a visual representation: card 15 contains two tables and was designed as a structured document. Students have a definite preference for card 13 followed by cards 11 and 4. Card 13 is a visual representation while cards 11 and 4 are mixed representations containing a diagram, structured text as a table or numbered list, and text. However students show an even more convincing dislike for all text cards with cards 1, 3, 14 and 16 scoring highly on the frequency table.

Card 12 is most frequently rated as easy, which is a mixed representation containing visual components. There is a consensus that cards 1 and 3 are difficult, with card 14 also been perceived as difficult.

When this data is grouped by representation type patterns are more easily identified.

Table 6.11 Student Constructs grouped by Representations Type

Represen t-ation Type	**Construct**									
	Visual	***Text***	***Like***	***Dis-like***	***Easy***	***Hard***	***Intro-duct-ory***	***Deep***	***Not dense***	***Dense***
All text 1,3,14,16	0%	79%	6%	70%	4%	81%	22%	54%	8%	43%
Structured 6,9,10,15	2%	16%	12%	18%	22%	13%	15%	15%	4%	25%
Mixed 4,5,7,12	42%	5%	42%	2%	37%	0%	35%	8%	42%	15%
Visual 2,8,11,13	56%	0%	40%	10%	37%	6%	28%	23%	46%	17%

The data in Table 6.11 illustrates that students are primarily differentiating between text and visual materials, evident in the constructs they have identified. Only 2% of students consider structured material to have some visual attributes, and only 5% of students consider mixed representations to be textual. All text materials are viewed by large percentages of students to be disliked, hard, require deeper reading and dense, with the reverse being true of materials containing visual components. If this data is grouped by the dichotomous student view of representation, i.e., visual and textual, the results are even clearer.

Table 6.12 Student Constructs Grouped by Textual and Visual Attributes

Student's view of Represent-ation Type	Construct									
	Visual	*Text*	*Like*	*Dis-like*	*Easy*	*Hard*	*Intro-ductory*	*Deep*	*Not dense*	*Dense*
Textual 1,3,14,16, 6,9,10,15	2%	95%	18%	88%	26%	94%	37%	69%	12%	68%
Visual 2,8,11,13, 4,5,7,12	98%	5%	82%	12%	74%	6%	63%	31%	88%	32%

As can be seen from Table 6.12 students are making clear distinctions between visual and textual materials. Textual materials are disliked, considered difficult, require deep reprocessing, and are dense to read, by at least 68% of students with 94% considering them hard. Conversely, more than 63% of students like visual materials, consider them easy to process, suitable as introductory materials and not dense to read.

Comparatively when this data is grouped by topic there are no real patterns emerging.

Table 6.13 Student Constructs Grouped by Topic

Topic Type	Visual	Text	Like	Dislike	Easy	Hard	Intro-ductory	Deep	Not dense	Dense
Compliers 1,5,9,13	27%	21%	27%	24%	22%	37%	25%	23%	**63%**	20%
Concurrency 2,6,7,14	28%	32%	23%	32%	26%	25%	25%	31%	25%	27%
Data types 3,4,8,10	21%	21%	21%	24%	15%	25%	20%	31%	8%	31%
E-R Modelling 11,12,15,16	24%	26%	29%	20%	37%	13%	30%	15%	4%	22%

As Table 6.13 illustrates there is a very even spread of perspectives and preferences across all topics, except for the compiler topic which students consider as not dense. On reviewing these documents the Compiler topic across all representations contains the most white space, which students report in the laddering activity to be a desirable feature. This will be examined later in this chapter. Conversely the E-R Modelling topic is a largely graphical topic, although the documents are quite dense as they contain a significant amount of information, similarly with the Data Types topic. However, overall, student preferences and perspectives do not appear to depend on topic.

The frequencies for these student constructs were correlated to assess relationships between them.

Table 6.14 Correlation Coefficients between Students' Visual, Like, Easy and Not Dense Constructs

Spearman's rho correlation coefficients	**Like**	**Easy**	**Not Dense**
Visual	.809** n=16	.769** n=16	.504* n=16
Like		.804** n=16	

In this table N = the number of cards

*(** indicates significant at the 0.01 level and * indicates significance at the 0.05 level)*

As Table 6.14 shows there are significant relationships between the *Visual* and *Like*, *Visual* and *Easy*, and *Like and Easy* constructs with a less significant relationship between *Visual* and *Not Dense.* The student group likes visual representations, considering them easy and not dense. However students demonstrated more strongly what they did not like.

Table 6.15 Spearman's rho correlation coefficients for the constructs Text, Disliked, Hard, Deeper Reading, and Dense

Spearman's rho correlation coefficients	Disliked	Hard	Deeper Reading	Dense
Text	.716** n=16	.699** n=16	.687** n=16	
Disliked		.834 ** n=16	.866 ** n=16	.695 ** n=16
Hard			.716 ** n=16	.607 * n=16
Deeper Reading				.456 n=16

In this table N = the number of cards

*(** indicates significant at the 0.01 level and * indicates significance at the 0.05 level)*

Table 6.15 above illustrates the relationships between these constructs. The student group did not like text, perceiving it as difficult to process, dense and requiring deeper reading. The information from the laddering process was used to define the meaning of these constructs. Table 6.16 combines summaries of the definitions students gave to their constructs. (See Appendix H for details of the verbatim definitions).

Table 6.16 Summaries of the definitions students gave to their constructs

Construct	**Definition of Construct gleaned from laddering exercise**
Like	This refers to the visual layout of the document. Documents must look inviting i.e., easy to understand with lots of white space and good mix and variety of representations, interchanging between text and graphics with some use of tables. Less text on the page is better as too much text is off-putting. Text and layout must be clear and not look like a book. Text needs section headings and must not be a straight block of text, which is dull. It must look interesting to the eye. Diagrams are preferred. Examples need to stand out from text. A graphic is better than tables with heavy lines. A good mix is 50% or more graphics with a max of 2 graphics per page. Text should be nicely spaced, with a font size no smaller than 10 point. The text should preferably be 2 columns per page as lines are shorter and easier to read.
Dislike	Dislike small text, small text in tables and too many diagrams that are cramped together. Inconsistency in the text is off-putting i.e.,- a little bit in a line and then a big bit in a line, doesn't look very easy to understand. *'Text that is all words with no gaps is dreadful'*.
Easy	Easy documents have lots of white space. White space it is better than too much/too large a graphic. Examples must be easily understood. Text must have headings. Easy is text summarised with tables. Sentence construction must be easy and consistent, and not too difficult to read.
Hard	This is something you wouldn't want to read, such as too much text - which is boring. Hard is where you have to read a line at a time - you can't skim read. Words in bold require work. Graphics not supported by text, giving information, are difficult. Dense documents are difficult to read. Tables can be difficult initially, although good later for summary.
Introductory	Suitable as something to introduce the topic.
Deeper Reading	More sophisticated or further understanding is required before reading it. Suitable for reference or for straight revising.
Not Dense	Lots of white space. Not dense is a mixture of graphics and reading. Worked examples look less off-putting. It doesn't throw you as much if it has graphics, tables and text.
Dense	Lots of information and lots of text on the page. Lots of words are claustrophobic. Card 16 looks denser because of the layout. Words seem to have more volume than graphics - an arrow can convey more meaning. Dense information takes up a lot of the sheet. It has a lot of black ink on the sheet and is a darker sheet of paper.

Students are quite clear that they don't like text. They find it boring and difficult to read. They also perceive this to be dense where lots of text in the document means lots of work so it is not inviting to read. Students are quite specific about what they do like, even articulating the preferred number of columns on a page, font size, number of graphics and the percentage of the document that should be taken up by visual representations. They do like documents with lots of white space and variety in representation. However, visual representations (graphics) are preferred. They are perceived as easier to process, being less dense and easier to read.

A clearly laid out document that is aesthetically pleasing is important. It must have section headings, visual representations and text to support them. Font sizes must be point 10 or greater and 2 columns are preferred. There must be no more than 2 visual representations in a page and they must not take up more than 50% of the document.

6.3.3.2 Academics' perception of visual representations

The academic data was analysed in a similar way to the student data. Table 6.17 shows the frequencies for cards in the commonly identified constructs Visual-Text, Like-Dislike, Easy-Hard, Introductory-Deeper Reading, and Not Dense-Dense (as for the student group in the previous section).

Table 6.17 Summary of the meanings of student constructs

Card	Description	Visual	Text	Like	Dislike	Easy	Hard	Introductory	Deeper	Not dense	Dense
1	Text: Compilers	0	6	1	3	1	1	2	4	5	0
2	Visual: Concurrency	6	0	1	3	0	2	1	5	1	4
3	All Text: Data Types	0	6	1	3	1	1	0	6	0	5
4	Mixed:: Data Types	4	2	2	2	1	0	1	4	2	2
5	Mixed:: Compilers	6	0	3	1	1	0	4	2	3	1
6	Structured Text: Concurrency	0	6	1	3	1	1	3	2	3	2
7	Mixed: Concurrency	6	0	3	0	1	0	3	3	1	2
8	Visual: Data Types	4	1	1	2	0	2	3	3	0	5
9	Structured Text: Compilers	1	2	0	4	0	2	0	6	0	3
10	Structured Text: Data Types	2	1	3	1	0	0	2	3	1	2
11	Visual: E-R Modelling	6	0	4	0	1	0	2	3	1	3
12	Mixed: E-R Modelling	4	0	3	1	1	1	3	1	1	3
13	Visual: Compilers	5	0	4	0	1	1	3	3	1	4
14	All Text: Concurrency	0	6	0	4	1	1	2	4	4	1
15	Structured Text: E-R Modelling	1	2	1	3	0	1	1	4	1	3
16	All Text: E-R Modelling	0	6	1	3	1	1	3	3	0	4
Total		45	38	29	33	11	14	33	56	24	44

While academics did identify text and visual representations as similar to those defined in this study, there was some difference between them as to what constituted structured text.

Some academics categorised structured materials as visual while others grouped them with text, and vice versa, i.e., cards 9, 10, and 15 which all contain tables were categorised by some academics as visual representations. This means that academics differed in opinion from what was defined in the study as text and visual and they also differed in opinion from the student group. Comparatively, only 2 students differed in this, one saw card 15 as a visual representation while the other perceived it as text.

There were only two academics that made a judgement on the Easy-Hard construct. It is included to illustrate the disparity of views between them. No other comparisons can be made with the data as the set is too small.

Academics most frequently perceived card 1, all text, as the least dense, followed by card 4 also an all text representation. These results differ from the student group. Students perceived card 1 to be dense with a frequency of 5. Similarly card 2 was perceived by academics as dense (f=4), while students perceived this as not so dense (f=5).

As with the student data the academic data is grouped by representation type in order to identify patterns.

Table 6.18 Academic Constructs grouped by Representations Type

Description	Visual	Text	Like	Dis-like	Easy	Hard	Intro-ductory	Deeper	Not dense	Dense
All Text: 1,3,14,16	0%	63%	10%	40%	36%	29%	21%	30%	37%	23%
Structured Text 6,9,10,15	9%	29%	17%	33%	10%	29%	18%	27%	21%	23%
Mixed 4,5,7,12	44%	5%	38%	12%	36%	7%	33%	18%	29%	18%
Visual 2,8,11,13	47%	3%	35%	15%	18%	35%	28%	25%	13%	36%

The patterns in the academic data, shown in Table 6.18, are not as clearly marked as in the student data. Academics did identify cards as being visual or text, although some did perceive structured text as being visual while others identified representations with visual components as being textual. Academics disliked all text and structured text documents, but they did not prefer visual representations to the same degree. They also considered all text documents to be as easy to understand as mixed representations containing visual components. Similarly there was no consensus on the other constructs either. When this data is grouped by the dichotomous student view of representation as either visual or textual (which academics also identified), the results are clearer.

Table 6.19 Academic Constructs Grouped by Textual and Visual Attributes

Description	Visual	Text	Like	Dis-like	Easy	Hard	Intro-ductory	Deep-er	Not dense	Dense
Textual 1,3,14,16, 6,9,10,15	9%	92%	27%	73%	46%	58%	39%	57%	58%	46%
Visual 4,5,7,12, 2,8,11,13	91%	8%	73%	27%	54%	42%	61%	43%	42%	54%

As can be seen by Table 6.19 academics are discriminating on text and visual and like and dislike. However, there is little difference between their views on these attributes on the other constructs identified.

When this data is grouped by topic there are no real patterns emerging.

Table 6.20 Academic Constructs Grouped by Topic

Description	Visual	Text	Like	Dis-like	Easy	Hard	Intro-ductory	Deep-er	Not dense	Dense
Compilers 1,5,9,13	27%	21%	28%	24%	27%	29%	27%	27%	38%	18%
Concurrency 2,6,7,14	27%	32%	17%	30%	27%	29%	27%	25%	38%	20%
Data Types 3,4,8,10	22%	26%	24%	24%	19%	21%	19%	28%	12%	32%
E-R Modelling 11,12,15,16	24%	21%	31%	22%	27%	21%	27%	20%	12%	30%

As can be seem from Table 6.20 academic preferences and perspectives do not appear to depend on topic.

The frequencies for academic constructs *Liked-Disliked, Introductory-Deeper Reading*, and *Not Dense-Dense* were correlated to assess relationships between constructs. A relationship exists between the *Visual* construct and the *Liked* construct (Spearman's rho=.683, n=16, p<0.01). However, frequencies in the data set *Liked*, were small (freq=4), which weakens this result. The results from the student group made a stronger statement about visual representations, i.e., they were liked, considered easy, and not dense. As with the student group, academics were more consistent about what they didn't like.

Table 6.21 Correlation Coefficients between Academics' Visual, Like, Easy and Not Dense Constructs

Spearman's rho correlation coefficients	Text	Disliked
Disliked	.765** n=16	
Deeper Reading		.611* n=16

*(** indicates significant at the 0.01 level and * indicates significance at the 0.05 level)*

Academics disliked text and considered it to be for deeper reading. The student group again stated this more strongly as they perceived text to be hard and dense also.

The information from the laddering process defines the meaning of these constructs. Table 6.22 summarises the definitions academics gave to their constructs. (See Appendix H for details of the verbatim definitions.)

Table 6.22 Summary of the meanings of academic constructs

Construct	**Definition of Construct gleaned from laddering exercise**
Like	The first impression must be very friendly and it must generate interest for the reader. It must be attractive and inviting, i.e., lots of white space - not filling the whole page. Documents should contain diagrams - a diagram gives a lot easily. Use progressive style of teaching. Diagrams can help you learn a lot without reading too much. Using bold can say, "I can help you". Shading can be useful..
Dislike	A style that makes you not want to read. Such as small fonts, busy diagrams using lots of arrows, everything close together, taking up margin space. Don't use lines in tables unless strictly necessary. Don't use uppercase - that's shouting.
Easy	A diagram used with labels and text that complement each other.
Hard	Complexity is a lot of information being put across. Diagrams can also be complex as there are indeterminate ways of reading it.
Introductory	This is a first reading for someone who doesn't know anything about the topic, i.e., less experienced. Used to convey important points for the first time reader. It shows information quickly without overwhelming, and directs the reader to the important information. Sets out the scenario that motivates and encourages the student to come on board as opposed to you just have to learn it. Introductory materials should include bullet points for overview, or diagrams, or an example to show what the concept is. An example can show why it is necessary and why it is useful.
Deeper Reading	This is for someone who already has some knowledge of the topic – advanced reading.
Not Dense	This is text with headings, tables, and graphics - a variety of types of object on the page. There should be different types of layout with plenty of space, important items should be weighted with bold and italics.... But not too much as in 10. The prettiest page is 13. This uses different types of representation: typefaces, bold, different shapes. Not dense is white space, wide margins, and gaps.
Dense	Density is a lot on the pages and lots of diagrams e.g. 3 diagrams. The reading route through the document is not very clear. *'It is also a lot of black on the page - like Springer-Verlag books where you have to physically scan everything with your eyes'*.

Academics like documents that are friendly and generate interest for the reader. Aesthetically the document must have lots of white space where information is not cramped together and it should be attractive and inviting. Documents should contain graphics (visual representations), as a diagram gives a lot of information easily without having to read too much. They perceive the use of bold as helpful to students. They don't like small fonts or busy diagrams and perceive uppercase as shouting. As few academics made the easy-hard distinction there is little in the way of a definition to describe it. However they did perceive diagrams to be complex, as there are indeterminate ways of reading it.

Other academic views included the fact that an introductory topic is for the less experienced (novices) and should offer the important information quickly. An example should set the scene to motivate as well as show why it is important. It should include bullet points and diagrams. A document that is not dense has headings, tables and graphics (visual representations) with lots of white space, using bold and italics to highlight important items, and should include wide margins. Dense documents have lots of black ink on the page and were compared to Springer-Verlag books, which are notorious in computing for having lots of information on each page.

6.3.3.3 How do the student and academic definitions compare?

A comparison of the laddering data as executed by Rugg et al. (in press) illustrated some interesting comparisons between novices and experts. Students repeatedly talked about the preference for diagrams all through their definitions, along with preference for white space. Documents that were poorly laid out with small fonts and cluttered presentations were perceived as difficult and dense, requiring more work.

While academics were in agreement with the student definitions they more specifically identified why diagrams are useful, i.e. they can give a lot of information more easily. However, they also identified that diagrams can be complex, as there are indeterminate ways of 'reading' them. Both agree that density is reflected by the amount of black ink on the page, whereas white space has the opposite effect. Students were more specific about their definition of liked. Font size should not be less than 10, there should not be more than 2 graphics per page, 2 columns of text are preferred, and examples should stand out from the text. Comparatively, the academic definitions were not so specific but gave underlying reasons for the usefulness of particular approaches and representations.

These perspectives are summarised in Table 6.23 to provide the following guidelines for what is desirable in instructional materials for students studying computer science at a distance.

Table 6.23 Criteria and guidelines identified by students and academics as important representational factors

Criteria	**Description**
Density	Lots of white space should be used to make the document inviting and interesting. Too much black ink portrays difficulty. Less on the page is better as too many words can be claustrophobic.
Diagrams	Diagrams should be used to help learning without reading too much. Diagrams should not be too busy with too much information. Arrows can convey more meaning than words.
Font	No font smaller than point 10 A style that is easy to read. Don't use uppercase. Use different fonts to represent different types of information.
Balance	Text and diagrams should complement each other
Information level	Introductory material should convey important points quickly and easily and should direct and motivate the reader.
Layout	Different headings should be used to denote level of information. Italics and bold can be used to weight the importance of words or concepts. The layout must not look like a book with dense text.
Columns	Two columns are preferred as this makes the column width shorter and thus is easy to read
Variety	Use a variety of representations to represent information.
Tables	Don't use tables with heavy lines as this is off putting
Examples	An example or bullet points can show what the concept is. Worked examples are more inviting than plain text. Examples should be easily understood.
Interest	It must look interesting to the eye and visually appealing,

The criteria identified in Table 6.23 are consistent with recommendations that Hartley (1994) makes for designing instructional text. While eliciting guidelines for representation in instructional materials was not an aim of this study, these are useful factors to consider in the development of instructional materials for this domain and mode of study.

Commonality comparisons of the card sort data, similar to research by Griffin (2000), Sanghera (2001) and Upchurch (1999; 2001), illustrated some interesting differences between the two groups. Academics did not make the same number of categorisations on these constructs as students did. Students made 45 categorisations in total on these constructs whereas academics made 24 categorisations in total. However, analysis of the constructs in terms of subjectivity and objectivity showed that academics were making more objective categorisations compared to students. Objectivity and subjectivity were categorised by an independent judge and the criteria were used in a similar way to research by Upchurch (1999; 2001). Objective constructs were observable and intrinsic such as 'size of font' or 'content'. Subjective constructs were judgements or preferences such as 'like', 'easy', and 'dense'

Table 6.24 Objective and subjective constructs of academics and students

Group	Number of Objective Constructs	Number of Subjective Constructs	Total
Students	54 68%	25 32%	80
Academics	67 81%	16 19%	84

As illustrated in Table 6.24 academics have a higher proportion of objective categorisations compared to students. This may account for the lower frequencies in the Visual-Text, Like-Dislike, Easy-Hard, Introductory-Deeper Reading, and Not Dense-

Dense constructs. Academics also appear to be making some more sophisticated categorisations. The following list exemplifies these.

- Immediacy – contains familiar personal things, familiar words, concepts relating to people
- The meaningfulness of the diagrammatic representation
- Abuse of graphical elements – not conveying any meaning
- The extent to which the combination of visual attributes and text imposes structure
- Mathematical abstraction
- Big picture versus the small picture
- More factual versus more descriptive information
- In what sequence to teach: Simple to Complex
- Obvious examples versus non obvious examples
- The extent to which the topic is introduced by motivating the student with a reason

However, there was not a great deal of commonality among academics on these more sophisticated constructs. Additionally, academics do not appear to be performing more sorts than students, which would be expected as an indication of expect-novice differences. Table 6.25 illustrates the number of categorisations that both groups performed by group and gender.

Table 6.25 The number of sorts by students and academics by group and gender

Group	**Single**	**Dichotomous**	**Triadic**	**Quadratic**	**Quintratic**	**Total**
Academics n=12	1	43	22	16	1	83
Students n=12	0	20	34	18	7	79
Gender						
Male n=12	1	34	31	16	2	84
Female n=12	0	29	25	18	6	78

Students were making fewer than half of the dichotomous sorts that academics were making. Academics frequently saw choice as one out of two possible options. Students' sorts are more sophisticated in terms of the number of categories compared to academics.

Table 6.26 The number of sorts by gender within group

Number of categories in sort	**Students**		**Academics**		**Total**
	Males	**Females**	**Males**	**Females**	
Single	0	0	1	0	1
Dichotomous	12	7	25	21	65
Triadic	20	14	12	12	58
Quadratic	9	9	8	9	35
Quintratic	2	5	0	1	8
Total	43	35	46	43	167

Incidentally, the literature suggests that males perform more dichotomous sorts than females (Gerrard, 1996). This is confirmed in this study as illustrated in Table 6.26.

However more females in the academic group were making dichotomous sorts than in the student group, by a factor of three. This raises some interesting questions as to whether the domain imposes certain practices on its professionals or whether professionals adopt certain characteristics when working in this domain. The gender differences in the number of categorisations performed is more apparent in the student group than in the academic group.

The average number of sorts varied little between groups with students having 6.58 sorts on average (SD=3.7s and n=79), while academics averaged 6.92 sorts (SD=1.78, n=83). There was little difference between gender. Males averaged 7.0 sorts (SD=3.81, n=84) and females averaged 6.5 sorts (SD=1.57, n=78). There was little variation by group or by gender on the average number of sorts performed. This represents an interesting result where academics as experts would be expected to perform more sorts (Rugg et al., 1992; Rugg & McGeorge, 1997).

6.3.4 What cards are perceived as similar and dissimilar?

Co-occurrence matrices (i.e. proximity matrices) were generated for students and academics to examine what cards were perceived as similar and what cards were deemed to be different. This is similar to the analysis performed by Griffin (2000). These frequencies were totalled together in a matrix to provide an overall view. This was performed for both groups. The student group is reviewed first.

6.3.4.1 Students' co-occurring cards

The following matrix shows the card numbers with the co-occurrence frequencies for the student group.

Table 6.27 Student card co-occurrence frequencies

Card No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		11	49	12	32	38	13	19	32	15	9	12	26	51	14	47
2	11		16	31	36	33	46	25	14	18	29	25	42	30	19	14
3	49	16		29	12	38	15	38	24	31	5	7	10	52	13	49
4	12	31	29		32	17	27	50	16	42	28	28	29	14	20	15
5	32	36	12	32		14	34	33	32	22	26	25	50	11	16	13
6	38	33	38	17	14		37	24	21	28	13	17	8	59	25	40
7	13	46	15	27	34	37		39	18	27	38	33	24	32	20	13
8	19	25	38	50	33	24	39		24	43	25	23	19	20	22	21
9	32	14	24	16	32	21	18	24		38	17	23	31	15	37	17
10	15	18	31	42	22	28	27	43	38		24	27	12	15	46	17
11	9	29	5	28	26	13	38	25	17	24		57	31	9	45	29
12	12	25	7	28	25	17	33	23	23	27	57		18	13	51	30
13	26	42	10	29	50	8	24	19	31	12	31	18		4	14	9
14	51	30	52	14	11	59	32	20	15	15	9	13	4		16	55
15	14	19	13	20	16	25	20	22	37	46	45	51	14	16		36
16	47	14	49	15	13	40	13	21	17	17	29	30	9	55	36	

The matrix of cards and their co-occurrences in Table 6.26 are presented by way of illustration, however they could be submitted to more substantial statistical analysis such as multi-dimensional scaling (see Hanisch et al., (1991) for an example). As the sample sizes are small, a visual comparison is sufficient for the purposes of this analysis.

Table 6.28, illustrating representation type and topic, is shown here to help readers interpret the results of the co-occurrence matrix.

Table 6.28 Card numbers, their representation type and their topic area

	Compiler	Concurrency	E-R Modelling	Data Types
Text	1	14	16	3
Structured Text	9	6	15	10
Mixed	5	7	12	4
Visual	13	2	11	8

In the following table, the cards are ranked by those most frequently co-occurring.

Table 6.29 Students 17 most frequently co-occurring cards ranked in order

Co-occurring cards	**Sort Factor**	**Frequency**	**Ranking of most frequently co-occurring**
14, 6	Topic	59	1
12, 11	Topic	57	2
14, 16	Representation	55	3
14, 3	Representation	52	4
14, 1	Representation	51	5
15, 12	Topic	51	
13, 5	Topic	50	7
8, 4	Topic	50	
16, 3	Representation	49	9
3, 1	Representation	49	
16, 1	Representation	47	11
15, 10	Representation	46	12
7, 2	Topic	46	
10, 8	Topic	43	14
13, 2	Representation	42	15
10, 4	Topic	42	
16, 6	Topic	40	17

Cards 14 and 6 both have concurrency as their topic area but have different representation types. Despite the fact that card 6 is structured text, with some numbered lists, students perceive little difference between the two representations.

Cards 12 and 11 and the second most frequently co-occurring cards (f=57). They both have E-R Modelling as their topic but are mixed and visual representations. The diagrams on both representations are of a similar type, although the visual representation does have more diagrams. The mixed representation has structured text in the form of a table; however, students did not appear to see this as different from the textual part of the representation in the visual form.

The third most frequent co-occurring cards are 16 and 14 (f=55). These are both textual representations for different topics. Even though they have different contents, students still perceive them to be similar.

The fourth most frequently co-occurring cards are 14 and 3 (f=52). These are both text representations for different topics. As with cards 16 and 14 they are perceived as similar regardless of the content.

The fifth most popular co-occurring cards are 15 with 12 (f=51), and 14 with 1. Cards 15 and 12 have structured and mixed representation within the E-R Modelling topic. Both of these representations contain similar looking tables, even though card 12 has diagrams and 15 does not. The tables appear to be providing some visual cue that both of these cards are similar. Cards 14 and 1 are both text representations for different topics.

The seventh frequently co-occurring cards are 8 with 4 (f=50) and 13 with 5. Cards 8 and 4 are the same topic having a visual and a mixed representation. Similarly with cards 13 and 5, both are on the compiler topic and have a visual and mixed representation.

Joint ninth in frequency of co-occurrence are cards 16 with 3 (f=49), and 3 with 1. All four cards are textual representations for different topics. Again those cards that have *text only* representations are deemed to be similar regardless of the content.

Eleventh in frequency are cards 16 and 1 (f=47). They are both textual representations for different topics also and similar to the previous co-occurrences are not differentiated by topic.

The twelfth most frequently co-occurring cards are 15 with 10 (f=46) and 7 with 2. Cards 15 and 10 are both structured representations for different topics. Similar to the all text cards topic they are not differentiated by topic. While cards 7 and 2 and mixed and visual representations within the E-R Modelling topic.

Cards co-occurring least frequently were also tabled. The following table illustrates the least often co-occurring cards.

Table 6.30 Students' least frequently co-occurring cards and their ranking

Co-occurring cards	**Sort Factor**	**Frequency**	**Ranking of least frequently co-occurring**
13, 14	Topic and Representation	4	1
11, 3	Topic and Representation	5	2
12, 3	Topic and Representation	7	3
13, 6	Topic and Representation	8	4
11, 1	Topic and Representation	9	5
14, 11	Topic and Representation	9	
16, 13	Topic and Representation	9	

The cards seldom co-occurring are 13 and 14 (f=4). These have different representations (visual and text) and different content (Compiler and Concurrency). These cards are visually quite different as well as having different content.

The second seldom co-occurring cards are 11 and 3 (f=5). These have different representations and contents also, i.e., visual and text, E-R Modelling and Data Types.

The third seldom co-occurring cards are 12 and 3 (f=7). Card 12 is also E-R Modelling but this time is a mixed representation, also seen as quite different.

The fourth seldom co-occurring cards are 13 and 6 (f=8). Card 13 is a visual representation for the compiler topic, while 6 is a structured representation for concurrency. Upon inspection these cards can clearly be differentiated in terms of representation as they are visually dissimilar.

The fifth seldom co-occurring cards are 11 with 1, 14 with 11, and 16 with 13. While these are three different co-occurrences there are similarities between them. Cards 1, 14 and 16 are all text representations within different topics Compiler, Concurrency and E-R Modelling, respectively. Conversely cards 11 and 13 are both visual representations within the topics Compiler and E-R Modelling. In these co-occurrences students are distinguishing between these cards in terms of representation and topic.

It is interesting to note that all text representations are not differentiated in topics E-R Modelling (16) and Data Types (3), i.e., they are co-occurring with a frequency of 49, and are seen as very similar. Yet cards that have visual representations in E-R Modelling (12) and all text representations in Data Types (3) are seen as different with a co-occurrence frequency of 7.

In fact cards 1, 14, 16, and 3 are all text representations in each of the four topics that co-occur with the highest frequencies in the matrix. These were also identified by students as difficult to process.

The following table shows the co-occurrences of these cards.

Table 6.31 Student frequencies of the co-occurrences of all text representations

Co-occurring cards all text representations	Frequency	Ranking of frequency
14, 16	55	3
14, 3	52	4
14, 1	51	5
16, 3	49	7
3, 1	49	7
16, 1	47	9

It appears that all text representations are seen as similar regardless of content, but where visual representations are used, students distinguish between topics.

6.3.4.2 Academics' co-occurring cards

The following matrix shows cards that co-occur in the academic group with analysis similar to the student group.

Table 6.32 Academic card co-occurrence frequencies

x	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		31	53	33	48	45	30	38	52	23	25	21	53	52	31	45
2	31		39	40	35	41	62	45	34	28	45	38	54	52	36	35
3	53	39		48	29	37	31	56	37	39	25	27	39	48	38	49
4	33	40	48		39	35	46	61	31	43	36	30	39	31	29	34
5	48	35	29	39		25	40	35	48	28	39	38	55	17	26	28
6	45	41	37	35	25		40	32	30	37	27	26	26	54	27	40
7	30	62	31	46	40	40		38	22	28	43	37	48	51	31	32
8	38	45	56	61	35	32	38		35	48	37	35	49	35	35	45
9	52	34	37	31	48	30	22	35		41	35	30	48	28	42	30
10	23	28	39	43	28	37	28	48	41		37	38	27	21	40	32
11	25	45	25	36	39	27	43	37	35	37		63	44	25	56	45
12	21	38	27	30	38	26	37	35	30	38	63		33	26	65	49
13	53	54	39	39	55	26	48	49	48	27	44	33		30	28	29
14	52	52	48	31	17	54	51	35	28	21	25	26	30		34	46
15	31	36	38	29	26	27	31	35	42	40	56	65	28	34		56
16	45	35	49	34	28	40	32	45	30	32	45	49	29	46	56	

In order to show the most frequently co-occurring cards, they are ranked by co-occurrence.

Table 6.33 Academics' 17 most frequently co-occurring cards ranked in order

Co-occurring cards	Sort Factor	Frequency	Ranking of most frequently co-occurring
15,12	Topic	65	1
12,11	Topic	63	2
7,2	Topic	62	3
8,4	Topic	61	4
8,3	Topic	56	5
15,11	Topic	56	
16,15	Topic	56	
13,5	Topic	55	8
14,6	Topic	54	9
13,2	Representation	54	
13,1	Topic	53	11
3,1	Representation	53	
9,1	Topic	52	13
14,1	Representation	52	
14,2	Topic	52	
14,7	Topic	51	16
13,8	Representation	49	17
16,3	Representation	49	
16,12	Topic	49	

The most frequently co-occurring cards are 15 and 12. Card 15 is a structured representation within the Entity-Relationship Topic and card 12 is a mixed representation within the same topic. The first half of both documents look similar as both contain similar looking tables, and they are both the same topic area. However card 12 has diagrams at the bottom of the table.

The second in frequency are cards 12 and 11. These are both within the Entity-Relationship topic and both have visual components. Card 12 is a mixed representation and card 11 is a visual representation. The diagrams in both are quite similar.

The third most frequently co-occurring cards are 7 and 2. Similarly these are both within the concurrency topic and both have visual components being mixed and visual, respectively. The commonality here is that they both contain diagrams that show the same concept but are different visually.

Fourth in frequency are cards 8 and 4. They too are visual and mixed, respectively within the data types topic. The commonality here is the visual representation of how a binary number is stored, although both are drawn differently.

Fifth are cards 8 with 3, 15 with 11, and 16 with 15. Card 8 is a visual representation while card 3 is a text representation within the data types topic. Although card 8 is a visual representation, the main difference between this and card 3 is the small diagram illustrating how a binary number is stored. Cards 15 and 11 are within the Entity-Relationship topic being structured and visual, respectively. The commonality here is topic and the layout, with both having lots of white space. However, card 11 does have a diagram. Cards 16 and 15 are both within this topic too, with card 15 being structured text. The accord here is topic area.

Next frequently co-occurring are cards are 13 and 5 within the compiler topic, being visual and mixed respectively. Both have one diagram that is similar (the first one), with 13 having three diagrams in total.

Ninth in frequency are 13 and 2. These are both visual representations in Compiler and concurrency topics, respectively. The commonality is that they are both visual representations although the diagrams are quite different visually and conceptually.

The tenth most frequently co-occurring cards are 13 with 1, and 3 with 1. Cards 13 and 1 are both in the compiler topic and cards 1 and 3 are both text representations, with card 13 being visual card 3 in the data types topic. The similarities with 1 and 3 are the textual nature of the representation while 13 and 1 are bound by topic.

The twelfth most frequently co-occurring cards are 9 with 1, 14 with 1 and 14 with 2. Cards 9 and 1 are the Compiler topic, consisting of a structured representation and text representation, respectively. They are not alike in representation with 9 having two tables, one of which is dominant: however they are bound by topic. Cards 14 and 1 are both text representations in different topics, Concurrency and Data Types, respectively. Cards 14 and 2 have topic as their commonality, with card 2 being a visual representation. Neither card is alike in representation. The next four set of co-occurrences are bound either by the same representation type of the same topic area. The four cards frequently co-occurring with each other are 11, 12, 15 and 16, and are all within the Entity-Relationship topic. Academics frequently see cards as similar that have the same topic. These were also identified by academics as requiring deeper reading.

Cards co-occurring least frequently were also tabled. The following table illustrates the least often co-occurring cards.

Table 6.34 Academics' least frequently co-occurring cards and their ranking

Co-occurring cards	Sort Factor	Frequency	Ranking of least frequently co-occurring
14, 5	Topic and Representation	17	1
14, 10	Topic and Representation	21	2
12, 1	Topic and Representation	21	3
9, 7	Topic and Representation	22	4
10, 1	Topic and Representation	23	5
11, 1	Topic and Representation	25	6
11, 3	Topic and Representation	25	
6, 5	Topic and Representation	25	
14, 11	Topic and Representation	25	
15, 5	Topic and Representation	26	7

All pairs of cards in the seldom co-occurring table are both different topics and different representations. Additionally no pair of cards contains visual components in both cards, i.e., there is no pair that has mixed representation and visual representation.

6.3.4.3 How do the groups' card co-occurrences compare?

The following table shows the student co-occurring frequencies compared with the academics.

Table 6.35 Difference in frequencies between the student and academic group for co-occurring cards.

Co-occurring cards	Student Frequency	Student Ranking of most frequently co-occurring	Academic Frequency	Academic Ranking of most frequently co-occurring
14, 6	59	1	54	9
12, 11	57	2	63	2
14, 16	55	3	46	27
14, 3	52	4	48	21
14, 1	51	5	52	13
15, 12	51		65	1
13, 5	50	7	55	8
8, 4	50		61	4
16, 3	49	9	49	17
3, 1	49		53	11
16, 1	47	11	45	28
15, 10	46	12	40	<28
7, 2	46		62	3
10, 8	43	14	48	21
13, 2	42	15	54	9
10, 4	42		43	<28
16, 6	40	17	40	<28

The biggest difference between the student group and the academic group is the co-occurrence of cards 14 with 16. These are both text representations but for different topics, yet students perceive them as being familiar, ranked 3 in their frequently co-occurring cards, compared with a ranking of 27 in the academic group.

A similar situation occurs with cards 14 and 3, ranked 4, with both being text representations for different topics. Students and academics are not sharing the same degree of agreement on the similarity of either set of these cards. The difference between students' most frequently co-occurring cards, 16 with 6, is not as great as these two co-occurrences; there is a difference in ranking.

Cards 14 and 6 are both in the concurrency topic although they are text and structured text representations. Text and structured text seem to be more readily perceived as the same thing by the student group, but not by academics, as cards with these representations are not as frequently co-occurring within their group. Academics first five ranked co-occurrences of cards were visually similar representations within topics.

Students' first two ranked co-occurrences were for similar representations within topic while the next three were for text representation between topics, i.e. even though the topic was different there were perceived to be very similar.

In summary, students more frequently perceive text representations between topics as the same and perceive text and structured text representations between topics as similar also. Academics tend to more frequently differentiate on topic seeing representations within topic as binding.

The frequency of cards considered as most similar was highest in the academic group i.e., 65 in the academic group versus 59 in the student group. Academics appear to have more agreement on what they perceive as similar.

6.3.4.4 Comparison of students and academics perspective on visual representations

As the students had a preference for documents that contain visual components, academic and student identification of representation types were compared. The number of constructs identifying documents containing visual components, either a mixed representation or a visual representation for each topic, were totalled.

5 out of 12 academics (42%) identified documents containing visual components as visual whereas **9 out of 12 students (75%)** identified documents with visual components as visual. This represents a difference in perspective. Academics may either not regard the distinction between representations as important as students do, or may regard it as taken-for-granted knowledge (Upchurch, 1999) that is too trivial to mention.

6.3.5 What value do the individual difference tests offer?

Individual difference tests were used in this study to confirm their value in predicating preferences for representation. As before a variable was constructed that reflected the degree of preference for visual representations. This was then used to test for associations with individual differences in learning. Thus a visual representation was weighted as 4, a mixed representation was weighted as 3 a structured representation was weighted as 2 and an all text representation was weighted as 1.

The total weighted score for preference for representation was correlated against the scores for the Group embedded Figures Test (GEFT), Wholist/Analyst (WA) and Verbaliser/Imager (VI) (both scores from the Cognitive Styles Analysis test) and from the scores in the Learning Styles Questionnaire on the four dimensions, Activist, Reflector, Theorist, and Pragmatist.

Table 6.36 Correlations of representation preferences with individual differences tests

Test	Result Description	Students	Academics	Both Groups
GEFT	Pearson Correlation	.075	-.097	-.012
	Sig. (2 tailed)	.816	.789	.959
	N	12	10	22
Wholist/Analyst	Pearson Correlation	-.042	-.019	-.004
	Sig. (2 tailed)	.896	.959	.984
	N	12	10	22
Verbaliser/Imager	Pearson Correlation	.073	.233	.189
	Sig. (2 tailed)	.823	.517	.400
	N	12	10	22
Activist	Pearson Correlation	.046	.107	.164
	Sig. (2 tailed)	.887	.769	.485
	N	12	10	22
Reflector	Pearson Correlation	-.522	.047	-.253
	Sig. (2 tailed)	.082	.898	.256
	N	12	10	22
Theorist	Pearson Correlation	-.566	.158	-.214
	Sig. (2 tailed)	.055	.663	.339
	N	12	10	22
Pragmatist	Pearson Correlation	-.300	-.030	-.123
	Sig. (2 tailed)	.344	.935	.585
	N	12	10	22

N = number of participants that stated an overall preference for type of representation

As Table 6.36 illustrates there is no relationship between any of these tests and preference for instructional materials. In this study the individual difference test scores were not indicative of any preference for representation in instructional materials for DE students studying computer science.

6.3.6 Has any student incidental learning taken place?

The pre and post tests scores were compared to assess whether any incidental learning had taken place, and whether any of these could be traced to visual representations. In the 48 possible cases for incidental learning to occur (i.e., 4 topics x 12 participants), 18 cases were identified, 16 of which were attributable to cards containing visual components and the other one was attributable to a document with structured text.

Table 6.37 Student incidental learning occurrences and reporting modes

Representation type	***Frequency***	***Representation used to report answer***
Visual and Mixed	16	4 reported visually 12 reported textually
Structured	1	1 reported textually
Unclear	1	6 reported textually

As can be seen from Table 6.37 students did not always reproduce the information in the form in which it was received, which indicates some internal processing and reorganisation is occurring even at a surface level. The visual representations that had the most incidental learning associated with them are listed in the following table, Table 6.38, with the frequency of occurrences.

Table 6.38 Frequency of cards traced to incidental learning

Card Number	**Number of occurrences**	**Type of representation**
2	5	Visual
4	1	Mixed
5	2	Mixed
11	2	Visual
12	2	Mixed
13	4	Visual

Table 6.38 illustrates that documents containing visual components seemed to be more likely to lead to incidental learning. These relate to preferences in visual representations in the following way, illustrated in Table 6.39.

Table 6.39 Student preference and Incidental Learning Frequency

Topic	**Card no**	**Incidental learning occurrences**	**Type of representation**	**Student Preference Frequency**
E-R Modelling	11 12	2 2	Visual Mixed	7 6
Compilers	13 5	4 2	Visual Mixed	8 4
Concurrency	2 7	5 0	Visual Mixed	5 5
Data types	4 10	1 0	Mixed Structured Text	7 3

Table 6.39 illustrates a relationship between student representational preferences and incidental learning. Personal choice and incidental learning appear to have some

relationship. The types of document that students prefer and have learned from incidentally, all contain a visual component such as a diagram. One student also identified card 13 in a sort group called "Key Recollection"; this student very clearly remembered information from this card and demonstrated incidental learning. He also drew a diagram very similar to the one on the card. However, these data sets are quite small and can only be suggestive as opposed to definitive.

6.3.7 How do academics decide on appropriate representations?

Academics were asked to bring an example of instructional materials that they had previously written to the case analysis interviews for discussion. They were asked about how they had developed the materials and when and why they had chosen to use particular visual representations. In general academics reported using visual representations:

- To break-up the text
- To have more white space on the page
- Because it was the best representation to use

Unfortunately there did not seem to be much more reflection upon the part of the academics beyond this. When academics were questioned further about why a particular representation that they had used was appropriate, they were unable to articulate their reasons.

6.4 Discussion

Students liked materials with visual components, finding them easy to process and inviting, and this is reflected in all aspects of the data analysed. Most importantly this indicates how influential visual representations are in cueing students to be receptive to instructional materials. The converse of this was also true in that *all text* documents were not liked, perceived to be difficult to process and required more work.

The card sort data married with the laddering data, provided information about perceptions on presentation. In fact students were quite specific about what they liked and what a preferred document should contain. This included the used of diagrams and ample white space on the page.

However academics were not this precise and did not state the same degree of preference for visual materials. Academics did identify why visual representations are useful to students as 'they give a lot, more easily', but at the same time were cautious enough to report that diagrams can be difficult, as there are an indeterminate number of ways of reading them. This is consistent with the literature of visual representations in that interpretations are personal and subjective (Richardson, 1999a).

The cards were considered informationally equivalent within a topic by 96% of the participants in this study who categorised the cards correctly by subject. Thus the level of information in each card was not a factor in the criteria for sorts. The data show repeatedly that visual representations are much preferred to plain text and are more accessible for students. Even if the document contains difficult concepts, the use of visual representations can cue students to perceive them as easier to process and learn from.

Additionally, the student co-occurrence data showed that text representations in different topics were perceived as similar, but not with visual representations. Hence visual representations were used by students to distinguish between topics and to identify important concepts.

Comparatively, academics shared a diluted perspective of this. Their categorisations were impoverished in breadth and depth, illustrated by individual stylistic sorts not shared by the group as a whole. This was a surprising result as the expectation was that academics, as experts, would have more extensive knowledge and should produce more sorts, but this was not borne out (Rugg et al., 1992; Rugg & McGeorge, 1997). However cards sorts do not elicit taken-for-granted or tacit knowledge (Rugg et al., in press; Upchurch, 1999; Upchurch et al., 2001) which might explain this.

When interviewed, academics did not reveal themselves as being anymore insightful about their own use of visual representations. During the case analysis interviews they did not demonstrate awareness about *when* they used visual representations, *why,* or *how* they decided on appropriateness. Their answers were superficial and not particularly illuminating. In fact some probing questions were met with a degree of resistance and hostility. This is a known phenomenon in knowledge elicitation, particularly when experts feel insecure about their knowledge (Tansley & Hayball, 1993).

To sum up, academics were unable to articulate why and when they used visual representations. This may be because they have intuitive knowledge that is difficult to express as card sorts do not elicit taken-for-granted or tacit knowledge (Rugg et al., in press), or because they simply have not reflected upon this process and really do not know. Additionally the academic group had a negative correlation between prior experience and visual representations. Thus visual representations may only be important and useful to novices who do not have enough experience to generate their own mental images (Dicheva & Close, 1996; Hanisch et al., 1991; Mayer, 1989; Merrill, 2000).

In conclusion, academics are not focussing on the same issues as students and the academic group is in less agreement as a whole. Academics are not illustrating themselves as reflective practitioners informed on issues of representation that ameliorate the difficulties of learning computer science in distance education. It may be that academics have forgotten what it is to learn (Durbridge, 1995) or have little experience in learning in a distance education mode and therefore are less concerned about the impact of representation. Additionally they may unconsciously be cued by their own preferences for representation when developing instructional materials. However, useful representation guidelines for instructional materials were generated from the student laddering data and embellished by the academic laddering data.

Guidelines presented in Table 6.23 reflect recommendations that Hartley (1994) makes in designing instructional text. However, this amplifies his work by adding information about the use of visual representations in instructional design for a DE context.

An incidental finding was that academics had twice as many dichotomous sorts as students, with students having the largest number of triadic, quadratic and pentadic sorts. This could be a reflection of the binary nature of the domain. Gerrard (1996) found that males use more dichotomous sorting than females which she concludes has interesting implications for decision making. While males did perform more dichotomous sorts than females there was a more interesting difference between the females in both groups. Female academics were performing almost three times as many dichotomous sorts as female students. There are a number of possible explanations. Female academics could be adopting characteristics that are inherent within the computing domain, or they are attracted to this domain because they possess these characteristics. Furthermore, females could be adopting male tendencies in a male dominated profession. At present there is no explanation available in the literature for this phenomenon and it is an area requiring more research.

None of the individual differences tests of the Group Embedded Figures Test (GEFT), Cognitive Style Analysis (CSA) and the Learning Style Questionnaire (LSQ), proved useful in predicting preference for representation.

The GEFT, measuring Field Dependence/Independence, showed no relationship with choice of representation. Nor was there any evidence to support the literature expectation that Field Dependent participants had a greater preference for structure (Jonassen & Grabowski, 1993; Witkin et al., 1971; Witkin & Goodenough, 1981; Witkin et al., 1977). As a means of predicting preference for learning materials, this test did not prove useful in this study. Richardson reports similar results in field dependence to measure autonomy of learning, experiences or predicting academic attainment (Richardson, 1998b).

Similar results were found with the Cognitive Styles Analysis test, measuring Imager-Verbaliser and Wholist-Analyst. Literature claims that Imagers prefer visual representations, while Verbalisers prefer verbal representations, were not borne out in this study. However, this preference may only exhibit itself in a learning situation. In this study participants did not choose materials that reflected their Verbaliser-Imager dimension.

This trend was repeated with LSQ, measuring learning style. No relationship was found between LSQ and preference for representation. Similar results were found in a previous study where there was no relationship with preference for communication mode in a computer science course studied by distance students (Carswell et al., 2000).

This study did not confirm the use of individual difference instruments as valuable for predicting preference for representation in instructional materials for distance education computing students.

This may be explained by the fact that the instruments were used in an artificial learning situation to predict preference in representation as opposed to preference in an actual learning situation. This also may provide some evidence for the argument raised in chapter 3 about the appropriateness of using generalised individual differences tests to examine learning issues in a specific task and context dependent situation. The majority of individual difference tests have been developed in artificial situations and they may not be suitable for use in practice-oriented research that is task and context dependent.

Results from the student incidental learning analysis indicated apparent relationships between preferred visual representations and improvements in learning. While the sample set is small, it tentatively suggests that visual representations may have some positive effect on learning and this is worthy of further investigation.

Text with visual representations are preferred for distance education as they can make students receptive to instructional materials, and even to difficult concepts. They can also be used to distinguish important information and they may be some benefit in learning conceptually challenging concepts.

6.5 Which visual representations are useful? – Focus for Study 2

Students responded positively to visual representations and this study shows that visual representations can cue students to perceiving documents as being easier to process and inviting. However, it is not clear what kind of visual representations can offer cognitive advantages for students, to help them overcome the difficulties of studying computer science at a distance.

As reviewed in chapter 4, there are variations in perspectives on the effectiveness of visual representations in learning. Mayer (1997) states that novices exhibit better problem-solving transfer performance when text is co-ordinated with visual representations than when only text is presented and that it enhances student understanding. However, he does not differentiate between types of visual representations. Conversely, Scanlon (1998) shows that including a visual representation was not helpful, so could the difference in results be due to a difference in the type of visual representation used?

Bertin (1981) argues that the type of visual representation can have an effect on how easily it is perceived. Abstract low-imagery visual representations are illustrations of reality with the omissions of attributes (Damerow, 1996). These omissions are often arbitrary and can render the representation far removed from the reality on which it was based offering limited explanation to learners. While low-imagery visual representations may offer conciseness for academics, as experts in the domain, novices are unlikely to be able to extract the same level of information without knowledge of what the omissions are. As experts can make their own mental images (Petre, 1990), a representation close to reality offering fundamental explanation of the concept is unnecessary. Additionally, diagrams that need to be read, where they have many labels or points on a graph, can have competing goals.

Based on dual processing theory (Kosslyn, 1980; Paivio, 1978, 1986; Richardson, 1999b) and a semiotic view of visual representations (Bertin, 1983), low-imagery diagrams need to be processed both verbally and visually. The quality identified by academics as advantageous in visual representations – 'that they give a lot easily' – would be lost. This may explain why some visual representations prove useful to students and others do not, as the cognitive load is affected by the degree of perceiving and reading required in visual representations. Thus, visual representations intended to ameliorate the difficulties of learning difficult concepts may not always achieve their goal.

A high-imagery visual representation should not require significant reading of symbols. It should intuitively evoke mental images salient to the individual that make the information easily perceived (Richardson, 1999b). Hence it facilitates more efficient dual processing of information, where textual and visual information can be processed in tandem. This is likely to be of use to novices that do not have enough knowledge or experience of the domain to develop their own mental images to facilitate learning difficult concepts.

To test this theory it is necessary to investigate what type of visual representation can offer cognitive advantages to students. In particular, to examine whether concrete high-imagery visual representations work best for novices in conceptually difficult areas compared with their abstract low-imagery counterparts.

6.6 Summary

This study examined the preferences and perspectives for visual representations in instructional materials for students studying a computing course at a distance. Information was elicited from both students and academics to compare and contrast expert-novice differences. Students were assessed for incidental learning to establish whether there was a link with representation. Academics were interviewed to explore representation design in developing instructional materials. Individual difference tests were used to establish their value in predicting preference for representation.

Results showed that the student group preferred materials containing visual components, as they perceived them as easier to process and inviting. They disliked *all text* materials perceiving them to be dense and difficult to process. Students used visual representations to distinguish between topics whereas all text representations did not afford the same distinction. This finding shows how influential visual representations are in cueing students to being receptive to information. It offers a powerful tool for engaging students in concepts that can present conceptual difficulties. Moreover, they can effectively be used to distinguish important concepts more readily than all text representations.

Useful information was gathered in the laddering activity from both groups, and this information provides guidelines for representation in instructional materials. While this was not an aim of the study it is a useful by-product that may assist computer science academics develop better instructional materials more in tune with the needs of distance students. They are also likely to be useful in the development of instructional materials for other scientific domains that contains abstract concepts.

The individual difference tests GEFT, CSA and LSQ were used in this study to assess their value in predicting preference for instructional materials. There was no relationship between preference for instructional materials and individual difference scores in any of the cognitive tests. In this study none of the tests proved useful. It may be that these types of tests are unsuitable for practice-oriented research examining episodes of learning.

Knowing how to represent information for distance learners is not an innate trait; academics need knowledge and understanding of the needs of their student group as well as knowledge and understanding of information representation and its effects. As visual representations are preferred by students and are perceived as easy to process, then further research is prompted into their use. As chapter 4 indicated there is variance in the results of the use of visual representations in learning. The next study will examine what kind of visual representation offers the best opportunity to ameliorate the difficulty of learning challenging computing concepts at a distance. In particular it will compare and contrast the use of high-imagery and low-imagery visual representations in learning. Chapter 7 reviews the role of visual representations in instructional material and describes the aims of Study 2.

Chapter 7 Visual Representations in Instructional Materials – Rationale for Study 2

7.1 Introduction

This chapter provides the rationale for Study 2. It extends the research in Study 1 where students demonstrated a preference for visual representations in instructional materials as they perceived them to be easier to process. Study 2 investigates the type of visual representation that might be useful in learning. A further review of the visualisation literature is included to illustrate the long-standing historical use of visual representations, their use in learning, and how they have been used in computing to concretise abstract and difficult concepts.

This leads to a description of the research aims of Study 2. These are described as a comparison of learning outcomes and learning processes when students are using two different treatments of instructional materials that contain either high-imagery or low-imagery visual representations. As an extension of the research in Study 1, individual difference tests are used to examine further their value in predicting learning behaviour and to assess their usefulness in task- and context-specific learning episodes.

The data requirements of this study are examined and data collection techniques are reviewed for their appropriateness. The chapter concludes with a description of the methodology for Study 2.

7.2 Rationale for Study 2

Study 1 has shown that students prefer visual representations in instructional materials and that these have the capacity to cue students to perceiving them as easier to process. However the literature review in chapter 4 illustrates that there is variability in results when using an additional visual representation to alleviate the burden of learning conceptually challenging concepts (Ainsworth et al., 1998; Dobson, 1998; Mayer, 1989; Mousavi et al., 1995; Oliver, 1997; Petre & Green, 1993; Scanlon, 1998).

One of the problems in comparing results is that visual representations are not easily distinguished. It may be that particular types of representations such as high-imagery or low-imagery are factors that affect the cognitive advantages that visual representations offer. The goal of Study 2 is to investigate this issue. In particular it examines whether there is any difference in learning when using high-imagery or low-imagery visual representations in instructional materials for teaching conceptually challenging areas for distance learning computing students.

Before examining the requirements of an investigation into different types of visual representations, the following sections will review the history of visual representations, their use in learning, and more specifically, their use in computer science.

7.3 Historical Review of Visual Representations

The use of visual representations is nothing new: they have enjoyed a long history in the '*written*' communication of humans. Long before the invention of writing, humans were recording early communications as symbolic and abstract pictures.

Some marks can be traced back as far as 35,000 BC where geometric type signs such as lines, bars, rectangles and other geometric shapes, could be found on the walls of caves in Spain and France during the Paleolithic period (Jean, 1989). Later they extended to drawings, paintings, and engravings on cave walls and could be found elsewhere in Europe, Africa and Asia.

These early forms of human communication are grouped together in clusters and are believed to convey specific meanings, even though they are unclear to today's viewers. Many of the drawings and symbols were permanent visible communicative representations long before the invention of the first writing systems at around 10,000BC. They are characterised by their use of signs to convey particular meanings and their repeated use, sometimes in a linear fashion. These were evident among indigenous peoples of North America, Egypt, and Greece, where they were used to convey messages, narrate stories, and define legal documents, being honoured in the same way as those written in language. Hence the use of visual representations historically predates writing as an enduring illustration of communication.

Maps are one example where visual representations operate successfully. They offer duality in information representation in that they abstractly represent spatial and textual information. The spatial quality enables a reader to interpret a position in relation to its place on the map and allows freedom to use the map in different ways for a variety of purposes. The use of legends doubles as an extra insurance that the coding mechanism in the map is augmented and interpreted as the coder intended it. The legend introduces a supplementary grammar into the map's semiologic system. Thus augmentation of visual representations with text and supplementary decoding cues helps readers to obtain the same intended meaning.

For example, a map that has no labels can give information about the terrain or layout of an area, but without text, no specific meaning or place name can be anchored to the terrain. Cartographers abide by strict rules in the design of maps to make them as accessible as possible in providing a multiplicity of information commonly understood (Bertin, 1983). These rules and conventions are taught in school and most adults have some knowledge of map reading to at least some minor level. So while it might be interpreted that abstract representations are easily accessible, the secret of their comprehension is due to consistency in use and knowledge and experience in interpretation.

Another example where visual representation of information has enjoyed success is in transportation systems (Jean, 1989). Railway signing was born in the early 19th century where signs were used to ensure the safety of railway workers and passengers. It used a simple binary system that was succinct and clear, indicating permissions to access limited resources such as single tracks, junctions and level-crossings. Mechanical semaphores and then electrical semaphores later replaced these. The conventions in these systems were made explicitly known to those who used them thus ensuring railway safety.

Road signs have their origins in safety too but their coding system is much more complex. They have an extensive coding system, with published guidelines on how to interpret them, using *colour* and *shape* to convey specific meanings. For example red represents danger and is used with circular signs convey prohibition. Road safety depends on a common interpretation of signs, and competence in the form of a theory test is required before a novice is licensed to drive.

In both of these examples the abstract representations used have been accompanied by strict rules for coding and interpretation. Unlike art that is open for interpretation, visual representations in this context are used to convey fixed meanings that require knowledge of the coding mechanism. They are concerned with interpretation, metaphors and reality, and the coder must guard against ambiguities and false signals to avoid interpretative variations. A key issue in developing a meaningful visual representation is that all the senders and receivers in the system should have a common knowledge of how to interpret it.

Diagrams can be used as schematic visual representations of phenomena employed to clarify concepts and they can be categorised in two ways: *representational and abstract* (Jean, 1989). Representational diagrams depict reality in a relatively proportional or literal manner. They often appear geometric and formal and yet many of these diagramming conventions are borrowed from nature: a road system looks like a spider's web and a family genealogy resembles a branching tree (Jean, 1989). In either case the underlying symbolism has concrete meaning in the real world and prior understanding of the diagramming conventions relieves interpretation biases. It allows the reader to navigate through the information, establishing meaning.

Abstract diagrams need bear no referential or proportional relationship to the things they represent (Jean, 1989), as the omission of qualities can remove them beyond association with reality (Damerow, 1996). While the examples of maps and transport systems illustrate how abstractions can work effectively, their success is attributed to strict rules and explicit knowledge of the underlying coding system. However an absence of this explicit coding knowledge can render a visual representation as an overhead rather than relief in learning.

Diagrams are frequently used in textbooks to aid understanding. However, in many cases the underlying principles of visual representations such as transparency or explicit coding knowledge are overlooked, adding ambiguity rather than clarity. This is evident in computing textbooks where abstract low-imagery diagrams are used to represent abstract concepts and the coding convention is borrowed from another topic, not transparent to the reader (for examples see Magee & Kramer (1999) and Patterson & Hennessy (1994)).

Readers of abstract low-imagery diagrams require explicit knowledge of the coding system so all can enjoy the same interpretation. In contrast, high-imagery diagrams can avoid misinterpretations, especially where the domain is not sufficiently rich or developed to have a coding mechanism in place. This legislates for high-imagery representations where the coding system is either transparent or explicit.

By using visual representations that relate to the real world then the likelihood of common understanding is greater for novices. Providing visual representations in instructional materials that do not account for coding comprehension leaves them open to misinterpretation (Scanlon, 1998; Scanlon & O'Shea, 1988). Regardless of the domain, effective visual representations that convey common interpretation require common understanding of the coding mechanism. It needs to be either intuitive, as a reflection of reality, or an abstraction where the coding mechanism is taught. The more explicit this coding mechanism is then the greater the chance of common interpretation (Bertin, 1983).

7.4 Visual Representations and Learning

Study 1 demonstrated how visual representations can cue learners to perceive instructional materials as easy and inviting. Mayer's (1989) work demonstrates that when visual representations are used in instructional materials students also have better problem-solving transfer performance.

For example, learning outcomes, assessed through post-tests, were better when novices used instructional materials where visual representations were co-ordinated with text as opposed to text only representations (Mayer & Anderson, 1991, 1992; Mayer, 1989, 1997; Mayer & Gallini, 1990). Others similarly concur (Cronbach & Snow, 1977; Snow & Yalow, 1982). However, Mayer (1997) confines his use of visual representations to concrete cause-and-effect explanations of simple scientific systems with students inexperienced in the domain, where the goal is meaningful learning. These factors may affect the nature of his results.

Conversely, Scanlon (1998; 1988) found that students did not benefit from having visual representations in instructional texts. Her research on novice physicists showed that it caused cognitive overheads as opposed to economies when they had an additional representation of a time and motion graph. Scanlon's findings are substantiated by other researchers such as Ainsworth (1998), Petre (1995) and Petre and Green (1993).

It may be that the type of visual representation used can have an effect on learning, illustrated in the concrete nature of Mayer's illustrations and the abstract nature of Scanlon's graphs. As discussed in chapter 4 there is no definitive way of differentiating between visual representations, so interpreting the difference between results is difficult. If visual representations are useful in learning then do different types offer qualitative differences in learning?

7.5 Visual Representations in Computer Science

Throughout the history of computer science humans have sought ways of using visual representations to help individuals understand abstract concepts in computing. In the 1960s flowcharts were used to visually represent the control flow of a program. They were aimed at supporting conceptual difficulties, enabling individuals to make explicit their own mental representation (Price, Baecker, & Small, 1998).

The continued growth of processing power enabled bigger and more complex programs. As an attempt to deal with this complexity, structured and object-oriented programming and design tools were introduced in the 1970s. These were developed to concretise these abstractions.

Through the 1980s experimentation continued with modularization, using graphical tools to provide visualisations of designs, while the 1990s saw a major move toward object-oriented languages with greater emphasis on visual design tools (Curtis, 1999). These automations of visual representations provided tools to observe enacting processes (Exton & Kolling, 2000; Feldman, 1992) or debugging tools to un-pick programming problems (Mulholland & Eisenstadt, 1998).

Historically the common theme has been the use of visual representations to alleviate difficulties in comprehending abstract computing processes. Using these to explain difficult concepts in computing has had a long and useful history. Where coding mechanisms have been made explicit, they have worked reasonably well, such as the software engineering design tools used in Jackson Structured Programming (JSP) and the Structured Systems Analysis and Design Method (SSADM). However, the use and interpretation of these tools is taught – it is not transparent.

Computerised software visualisations have become popular methods of reducing abstraction in software development. However, there are mixed results as to their effectiveness (Cant, Jeffery, & Henderson-Sellers, 1995; Cross, Maghsoodloo, & Hendrix, 1998; Curtis, Sheppard, Kruesi-Bailey, Bailey, & Boehm-Davis, 1989; Goolkasian, 1996). Petre et al. (1998) question which audience visualisations are aimed at supporting, and as Petre (1990) points out novices and experts have different needs. Additionally, the same visual representation may not be perceived identically by different users (Heath, Allen, & Rover, 1998; Richardson, 1999a, 1999b). However, visual representations do not have to be automated to be useful. Hendrix et al. (2000) have had successes with static visual representations such as control structure diagrams (CSD).

Collectively, visual representations have an intuitive appeal and may be more readily understood than textual information in this context (Baecker, 1998; Hendrix et al., 2000). Visual high-imagery representations have a historical and reoccurring place for learners in this abstract domain. The aim of these uses of visual representations is to enable humans to understand how a machine processes a human's solution to a problem. Given the abstract nature of computing, a representation that concretises difficult concepts can provide learners with more meaningful information (Ausubel, 1963) enabling them to relate abstract concepts to personal and more meaningful previous experiences (Taraban, 1993).

As described in chapter 2, concurrency is one such area that presents learners with difficulties (Adams et al., 2000; Ben-Ari & Kolikant, 1999; Choi & Lewis, 2000;

Exton & Kolling, 2000; Feldman, 1992; Hailperin et al., 2000; Hendrix et al., 2000; Jackson, 1991; Naps & Chan, 1999; Yeager, 1991). Conceptual problems centre on understanding how processes can run in parallel (Exton & Kolling, 2000). Students seem unable to relate the theoretical basis of this to concrete experiences of their own (Ben-Ari & Kolikant, 1999), so a visual representation may offer assistance in making these connections.

Stenning et al. (1995) used visual representations in the teaching of logic. They compared the use of visual representations with teaching logic in a traditional syntactic method. They found that visual representations were useful in helping students to understand logic. They also examined individual differences in order to assess analytical reasoning. They found that there were strong interactions between individual differences and methods of teaching. Those who had low analytical reasoning benefited most from using visual representations.

Zhao et al. (1994) used visible links to improve learners' conceptual understanding of how to navigate in a hypertext environment. They used an approach that examined learning outcomes as well as learning processes in the comparison between the use of visible and non-visible semantic relations. The research showed that using visible links to explain semantic relations had a positive effect on learning. They also found that learners with lower learning pre-requisites benefited more from visible links than those with higher learning pre-requisites.

Bayman and Mayer (1988) have used visual representations to teach the programming language BASIC where illustrations showed the state of a machine before and after each statement execution. They compared materials that had no illustration with those that had. They examined individual differences in ability as they predicted that low-ability students would benefit more from visual representations. Post-tests were used to examine semantic and conceptual or functional knowledge. They found that the use of visual representation was effective in improving instruction, but that these effects were strongest in the weakest students. They also demonstrated a link between improved problem solving ability and increased conceptual knowledge.

These studies all appear to indicate that those that are novices or have lower abilities benefit most from using visual representations. So part of the examination in Study 2 considered whether novices learned any better when using high-imagery visual representations compared to low-imagery ones. The endeavour in Study 2 was to use effective visual representations to support the learning of difficult concepts such as concurrency for novice computer scientists.

7.6 Research Aims of Study 2

The aims of Study 2 were to examine the cognitive advantages of using high-imagery compared with low-imagery visual representations in teaching difficult topics to computer science students studying at a distance. The prediction was that concrete high-imagery visual representations used with text in instructional materials would offer cognitive advantages compared with their abstract low-imagery counterparts.

Participants were required to study two different treatments of visual representations where concurrency was the exemplar of a conceptually difficult area. To examine how these different treatments affect learning required an assessment of learning outcomes and learning processes, similar to the approach adopted by Zhao et al. (1994). This was to examine whether high-imagery visual representations had an effect on different types of learning such as syntactic or functional learning and to assess whether either representation offered cognitive advantages. As with Study 1, triangulation is used to examine the research question from a number of perspectives. These perspectives are illustrated in the research plan for Study 2 in Figure 7.1.

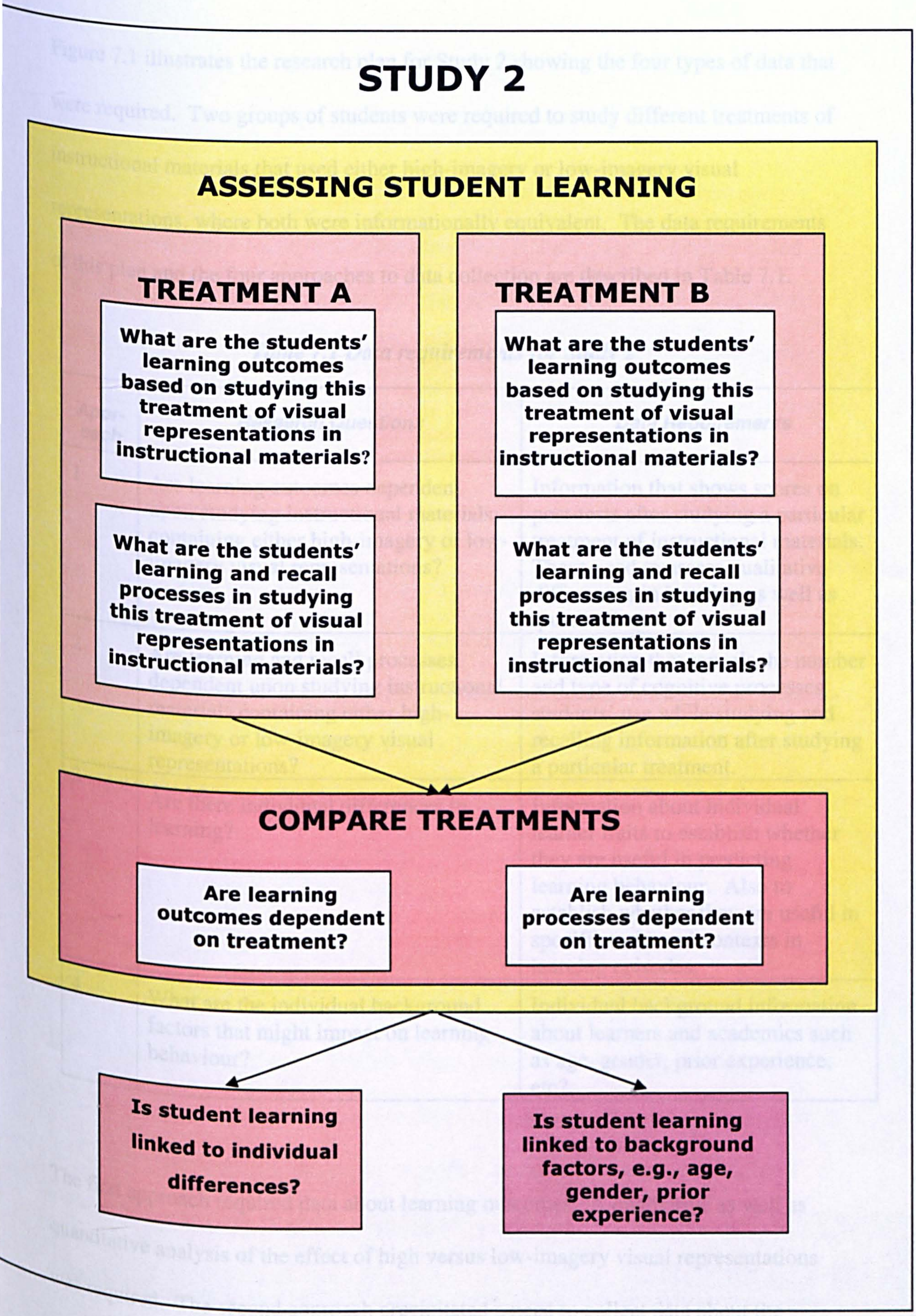


Figure 7.1 Model of Research for Study 2

Figure 7.1 illustrates the research plan for Study 2 showing the four types of data that were required. Two groups of students were required to study different treatments of instructional materials that used either high-imagery or low-imagery visual representations, where both were informationally equivalent. The data requirements of this plan and the four approaches to data collection are described in Table 7.1.

Table 7.1 Data requirements for Study 2

Appr-oach	**Research Questions**	**Data Requirements**
1	Are learning outcomes dependent upon studying instructional materials containing either high-imagery or low-imagery visual representations?	Information that shows scores on post-tests after studying a particular treatment of instructional materials. These need to assess qualitative differences in learning as well as quantitative.
2	Are learning and recall processes dependent upon studying instructional materials containing either high-imagery or low-imagery visual representations?	Information that reveals the number and type of cognitive processes students' use while studying and recalling information after studying a particular treatment.
3	Are there individual differences in learning?	Information about individual learner traits to establish whether they are useful in predicting learning behaviour. Also to establish whether they are useful in specific tasks and contexts in learning episodes.
4	What are the individual background factors that might impact on learning behaviour?	Individual background information about learners and academics such as age, gender, prior experience, etc?

The first approach required data about learning outcomes. A qualitative as well as quantitative analysis of the effect of high versus low-imagery visual representations was required. The second approach precipitated a need to collect data about the cognitive processing incurred in using either set of materials. The third and fourth approaches to data collection were the same as those used in Study 1.

While Study 1 revealed that the individual difference tests were not useful in predicting preference for representation, this may be due to their use in predicting preference as opposed to behaviour. In chapter 3 it was argued that the individual differences tests might not be appropriate approaches to examining specific learning tasks that are domain and context specific. The tests were used in Study 2 to examine whether individual difference tests were useful for predicting learning in a task- and context-specific learning episode.

The first data collection approach required rich data on learning outcomes after students had studied either treatment of instructional materials. The second approach required data about the cognitive processes students used while studying and recalling information. The following section reviews student learning and assessment for appropriate approaches to facilitate the data requirements of this study.

7.7 Student Learning and Assessment

Assessing student learning requires an understanding of what is being assessed. Deep learning can be characterised as an approach to learning that results in an outcome demonstrating a level of understanding where learners can make arguments and relate them to evidence in the material, and to personal experience (Marton & Säljö, 1976). Surface level processing is where learners direct attention to the text itself using a reproductive scheme to learn, i.e. adopting a rote-learning strategy.

Ausubel distinguishes rote learning from meaningful learning in much the same way that Marton distinguishes between surface-level processing and deep-level processing.

Ausubel's (1963) view of meaningful learning is that learners must employ a meaningful set and that the material must be potentially meaningful to them. Learners must see the material as something meaningful otherwise the process of learning becomes rote and the internalisation of the material consists of arbitrary associations. Even if the components of the material are meaningful (i.e. students are aware of their meaning), unless the task itself is meaningful, then rote-learning occurs. Meaningful learning has a cognitive set which incorporates relationships with other cognitive sets that support derivative, elaborative, correlative, supportive and qualifying relationships.

Conversely rote learning, while relating to other cognitive structures, leads to a cognitive set with an arbitrary structure. The difference in outcomes of these types of learning are portrayed as trial and error in rote-learning and insightful problem solving in meaningful learning. If visual representations are used in learning they must be perceived by learners as meaningful if they are to use deep approaches to learning, otherwise they may revert to rote memorisation strategies. Using concrete visual representations may help to make representations meaningful to the learner where the task is meaningful and so enable associations with previous experience or knowledge (Ausubel, 1963).

Taraban (1993) offers a more current and increasingly popular view of learning stimulated by an interest in artificial intelligence. He uses a connectionist model to characterise learning. This focuses on two factors: background knowledge and exposure to instances—these contribute to what is known as category learning and processing. Learners construct their internal representation of a category based on prior knowledge and experience as these are bound to affect how individuals learn

(Hartley, 1998). Where the category is biased and the background knowledge is incomplete or imperfect it is revised accordingly. In this model the categories are fuzzy and the connections in the processing units are weighted to cue levels of importance in the relationships. These too are revised if the background knowledge is incomplete or imperfect.

Taraban's model offers some level of fluidity for understanding the internal representation of knowledge. However it is data-driven and characterises a model based on attributes as opposed to functionality. Nevertheless the fluidity of his model is attractive and removes the barriers of perceived rigidity in classifying a learner's internal structure of knowledge.

Enabling students to relate what they perceive in a visual representation to a concrete or previous experience, would support Taraban's view of how learners learn. A concrete representation would enable students to make links with other knowledge or experience and could additionally support Ausubel's view of making the learning self-meaningful. Therefore a more concrete high-imagery visual representation may enable stronger connections with other knowledge.

The nature of computer science makes it difficult to teach given that its artefacts are invisible and not detectable to human senses. This requires learners to develop mental representations of abstract processes in order to reason about their behaviour. Wiedenbeck at al. (1993) have shown that novices rely on concrete information whereas experts use functional information. Their research showed that novices used syntactic knowledge and illustrated inexperience in developing programs. In contrast, experts used conceptual or functional knowledge (Petre & Green, 1990; Wiedenbeck, 1986). The effect of this is that novices often have the ability to construct programs using syntactic knowledge but are not able to explain and predict process behaviour, particularly in novel circumstances (Dicheva & Close, 1996).

To address the difficulties of teaching computer science to novices, concrete and visible illustrations are used to help them learn (Bayman & Mayer, 1988; Dicheva & Close, 1996; Du Boulay et al., 2001; Du Boulay et al., 1981; Oliver, 1997). Instruction in computer science needs to encourage the development of mental representations that support functional as well as syntactic knowledge and may need to support novices' concrete requirements for information.

Developing qualitatively richer forms of learning to encourage the development of functional and syntactic knowledge is a challenge. This can be observed in other areas of learning, such as mathematics. Wertheimer (1945) indicates that frequently the wrong emphasis is placed by teachers on getting homework problems right. He describes a study on children who are given a mathematical formula to solve the problem. The research showed that although they could use the formula without mistake, they were not able to articulate what problem they were solving or actually understand the theory behind it.

This has parallels with novice programming behaviour where trial and error strategies are used to problem-solve in absence of functional knowledge (Wiedenbeck et al., 1993; Zweben et al., 1989). Thus a strategy that assesses 'correctness' makes a quantitative and not qualitative assessment of learning that describes syntactic knowledge as opposed to functional knowledge.

In education the focus on assessment is not necessarily to test for deep and meaningful learning where a student's ability to construct, explain, and predict are tested. Many assessment procedures focus on 'how much' is learned, as though knowledge were quantifiable (Dahlgren, 1978). While the goal of exams is often to pass students and test a variety of levels of learning, the assessment procedures themselves can cue students to learn at either surface or deep levels depending upon what they perceive the assessment criteria to be (Scouller, 1998).

Mayer (1989) takes a qualitative approach to assessing learning, where knowledge transfer is tested as a result of deep and meaningful learning. He argues that examining meaningful learning must include an examination of different types of knowledge. His work shows that novice students performed better on problem solving activities when illustrations were used (Mayer, 1989, 1997; Mayer & Gallini, 1990).

Mayer used three different types of tests to examine different aspects of learning. The *recall* post-test required students to write down all they could remember as though they were writing an encyclopaedia for beginners. This was used to assess the level and amount that students had learned. The *transfer* post-test consisted of five different questions that tested students functional knowledge, where they had to answer *'what happens next'* type questions. This was to assess the level of functional knowledge students displayed by their ability to predict events in a model. The *verbatim recognition* tests consisted of eight pairs of sentences, where one occurred verbatim, as in the text, and the other was re-worded. This was to assess whether students were learning at a superficial level where information was stored in verbatim form.

Post-tests alone cannot reveal whether a representation is causing cognitive overheads for students. It may be that students use strategies to compensate when faced with representations that they find difficult to process. Post-tests and other external observation techniques cannot offer information about the internal cognitive processes of a learner. Only inferences can be made from observations and they may not be appropriate. Weinberg (1971) recognises this problem and states

> Because programming is such a rich and complex activity, we shall need all the richness of methods and results we can borrow from all of the behavioural sciences (p39).

While some view introspection as non-scientific analysis it forms the foundation of other sciences. Without introspective analysis of the mental elements of speech, the doctrine of aphasia would have been impossible (James, 2001/1961). Weinberg promotes the use of introspection as a valuable means to understanding how humans perform programming tasks. He argues that investigation without introspection is sterile and introspection without investigation is questionable.

Svensson's (1977) used introspective analysis to examine learning processes in detail to be able to explain, rather than describe, performance. The reports were retrospective as opposed to concurrent where students' reports were collected after the event. Ericsson and Simon (1984) refer to this approach as protocol analysis and theoretically describe it in the following way.

> *Our general model for this assumes that the cognitive processes leave in LTM a subset of the originally heeded information in the form of a retrievable trace of connected episodic memory. Retrospective reporting involves retrieval of these episodic memories (p149).*

Svensson's use of introspective analysis involved retrospective reporting of students' learning processes. Students were asked to recall how they had studied the material directly after the learning activity. As already discussed in chapter 5, post learning questionnaires are an appropriate and valid means of obtaining retrospective reports and have the advantage over concurrent reporting in that they do not interfere with the processing of the task itself (Richardson, 1998a, p611). The data from these reports can then be subjected to protocol analysis, where the reports are encoded into protocols that describe steps or actions in a process.

There are objections to this approach on the basis that the time lag between the cognitive activity and the report causes participants to forget a particular strategy used (Groninger & Groninger, 1984). Further, the lack of accurate information causes participants to rely on inferences and re-enactments (Nisbett & Wilson, 1977). It is possible to instruct participants to report concurrently during processing. However this changes the nature of the task where participants may use additional strategies due to the nature of the explicit instructions (Richardson, 1998a).

Ericsson and Simon (1984) argue that reports collected directly after the task generate largely accurate reports; "This form of retrospective report should give us the closest approximation to the actual memory structures" (p19). Using introspective reports retrospectively can provide knowledge of the cognitive processes that students use during a learning episode.

Mayer's use of post-tests offers an appropriate means of collecting learning outcomes that enables an examination of syntactic surface-level knowledge and functional deep-level knowledge as a result of studying either representation. Retrospective reporting offers a data collection technique of the students' learning processes to investigate the cognitive advantages and economies that either representation offers.

7.8 Methods Used

Study 2 examines performance through post-tests, and cognitive processing through introspective reports, using the same measures for both treatments. To collect these different types of learning assessing the difference between syntactic and functional knowledge, post-tests were modelled on Mayer's work (1989) testing for verbatim, recall and transfer knowledge.

The introspective reports were modelled on Svensson's (1977) work and influenced by Richardson's (1998a). Post-learning questionnaires were used to retrospectively collect students' reports of their cognitive activities in learning and recall processes. These reports were expected to inform why concrete high-imagery visual representations might offer some cognitive advantage compared to abstract low-imagery visual representations.

Table 7.2 illustrates the methods used to facilitate the data requirements for Study 2. The post-test is modelled on Mayer's (1989) work as it offered a method of assessing the quality of learning as opposed to a quantity-only perspective. The introspection reports are modelled on Svensson's (1977) work as these informed about the cognitive processes in learning and recall activities enabling explanation of learning outcomes.

Table 7.2 Data requirements and techniques used in Study 2

Research Questions	**Data Requirements**	**Data Collection Technique**
Are learning outcomes dependent upon studying instructional materials containing either high-imagery or low-imagery visual representations?	Information that shows scores on post-tests after studying a particular treatment of instructional materials. These need to assess qualitative differences in learning as well as quantitative.	• Verbatim, Recall and Transfer Post-tests. These are modelled on Mayer's use of post-tests
Are learning and recall processes dependent upon studying instructional materials containing either high-imagery or low-imagery visual representations?	Information that reveals the number and type of cognitive processes students' use while studying and recalling information after studying a particular treatment.	• Retrospective reports Students complete reports on how they studied and how they recalled information after the activities. Protocol analysis is used to analyse the data.
What are the individual differences in learning?	Information about individual learner traits to establish whether they are useful in predicting learning behaviour. Also to establish whether they are useful in specific tasks and contexts in learning episodes.	• Group Embedded Figures Test • Cognitive Styles Analysis Test • Learning Styles Questionnaire
What are the individual background factors that might impact on learning behaviour?	Individual background information about learners and academics such as age, gender, prior experience, etc?	• Background Questionnaire for students

Study 2 also uses the same individual difference tests and background questionnaires as in Study 1. In this study individual difference tests were used to assess their value in predicting behaviour in a learning situation. In particular, given the results of Study 1, it was important to further evaluate their usefulness in task- and context-specific episodes in learning.

The Group Embedded Figures Test (GEFT) was used to test field independence, Cognitive Style Analysis (CSA) was used to assess Verbaliser/Imager and Wholist/Analyst, and the Learning Style Questionnaire (LSQ) was used to assess general learning style. The background questionnaire was the same as that used in Study 1 and is similar to Bayman and Mayer's (1988). This was used to check whether any learning enhancements could be attributed to other factors, such as age, gender, and prior knowledge.

7.8.1 The Instructional Materials

The topic area used as an example of a conceptually difficult area was concurrency. The instructional materials were aimed at introducing the topic of concurrency to novices. There were two versions of the instructional materials (see Appendix I for an example of the materials). Both were informationally equivalent but differed in the type of visual representation used.

Treatment A contained text with abstract low-imagery visual representations and treatment B contained text with concrete high-imagery visual representations. As discussed in chapter 4, high-imagery is defined as a visual representation that spontaneously evokes a mental image in an individual while a low-imagery representation presents difficulties (Richardson, 1999b).

The concrete high-imagery diagrams used entities that closely resembled real world artefacts while abstract low-imagery diagrams used entities that had no direct link with the real world. There were five figures used in total in each treatment. The participants were given the materials and asked to study them as they would do in their course. They were given 30 minutes to study the materials but were allowed longer if necessary, which was noted.

7.8.2 Assessing Learning Outcomes: Post-tests

The goal of the post-tests was to establish the quality of learning and whether visual representation type affected performance, particularly in problem solving. The post-tests for Study 2 were modelled on those used by Mayer (1989) assessing verbatim, recall and transfer knowledge.

The *verbatim* test consisted of eight pairs of sentences where one of each pair occurred verbatim in the text and the other was a reworded version. Students had to identify which sentence occurred verbatim in the text. The *recall* test required students to write down all they could remember about what they had studied. The *transfer* test consisted of five questions that asked explanatory questions requiring systematic thinking. The goal was to test whether participants had some underlying model that supported problem solving transfer (Mayer, 1989).

The tests in Study 2 were designed using this model to assess the quality of learning when using either high-imagery or low-imagery visual representations. Discussions with Mayer (2000) indicated that he did not consider the verbatim tests particularly useful, however for completeness in modelling his work they were included.

A further extension was made to the transfer post-test to explore the types of problem solving students perform. This was to distinguish between different types of problem solving observed in students. In Study 2 the goal was to enable students to *explain* and *predict* and not just *construct*, because this was seen as indicative of expertise and comprehensive understanding.

The tests similarly reflected scrutiny of these levels of understanding. The modified recall test was designed to distinguish between levels of learning displayed in each test. It had three part scores of Explain, Predict and Construct (Construct had two part scores of Reproduce and Create), to examine whether the type of visual representation affected any of these levels of outcome, illustrated in Table 7.3 (See Appendix J for an example).

Table 7.3 showing the type of questions used in the post-test in Study 2

Type of test	***Requirements***	***Time allowance***
Recall	Students were required to write down all they could remember and to pretend they were writing an encyclopaedia for beginners	20 minutes
Transfer This test was broken down into sub areas: *construct-reproduce* *construct-create* *explain* *predict*	For all of these types of questions students were required to answer specific questions in order to examine syntactic and functional knowledge. Scenarios were used to set the scene for some of these questions. In total there are 10 questions.	35 minutes
Verbatim	Students were required to identify a verbatim sentence from a pair of sentences. They were required to tick a box indicating the correct sentence. In total there are 12 pairs of sentences.	2 minutes

The post-test was administered to participants after studying the learning materials. The time limit for each test is indicated in Table 7.3.

7.8.3 Assessing Learning Processes: Introspective Reports

The introspective reporting technique was modelled on Svensson's (1977) work and influenced by Richardson (1998a). This technique was reviewed in chapter 5 section 5.5.4 on page 103. This review argues that post-learning questionnaires are a valid means of collecting retrospective self-reports on episodes in learning (see Richardson,1998a, for a full review of this debate). Retrospective reports collected by this method have been shown to be accurately retained for up to a week (Adams et al., 1969). Additionally the use of retrospective reports avoids cueing students to use mediators more than they might do in the absence of such instruction (Richardson, 1998a).

Post-learning questionnaires were used to collect retrospective reports of two types of processes: learning processes and recall processes. Participants were required to report on how they had studied the instructional materials during the learning activity and how they had recalled information in the post-tests. Participants completed the learning processes report after the learning activity and the post-test activity. This was to prevent participants being cued in advance for either test or report. In each case they were instructed to report on how they had conducted each activity: i.e., after the learning task they were asked to report, from memory, how they had approached the process of learning, including what they were thinking, different tactics they may have used, and the types of things they did during this procedure. Similar instructions were provided to participants regarding the completion of the retrospective reporting of their recall processes in the post-test activity. These instructions, for both learning and recall processes, were reinforced by printed instructions at the front of the retrospective post-learning questionnaires (see appendix J for an example of the instructions).

The purpose of this data collection was to investigate how two different treatments of visual representations effect learning processes and recall processes.

7.9 Summary

This chapter provided the rationale for Study 2 that extends the research in Study 1 to investigate the type of visual representation that might be useful in learning. A further review of the visualisation literature was included to illustrate the long-standing historical use of visual representations, their use in learning, and how they have been used in computing to concretise abstract and difficult concepts.

The review illustrates the reason for the intuitive nature of visual representations as a method of communication and discusses areas where visual representations have a long and successful history such as in cartography. It explains the success of visual representations as those having either explicit formalised coding systems, understood by readers, or as intuitive concrete representations with transparent coding mechanisms.

The work of Mayer and Scanlon was reviewed to illustrate the use of visual representations in learning and their effects. Scanlon's work illustrated that visual representation were not useful whereas Mayer's work offered evidence for their success. The chapter discusses the possible reasons for variance in results and hypothesises that concrete high-imagery visual representations can help students learn in conceptually difficult areas.

The use of visual representations in computing is discussed, illustrating that they have been used since early computing years to relieve abstraction. A review of research on the use of visual representations in computer science education suggested that novice or low-ability students benefited more from visual representations and thus may benefit more from high-imagery visual representations.

The review of this literature leads to a description of the research aims of Study 2. The goal of this study was to investigate what kind of visual representations could offer cognitive advantages. These were investigated as a comparison of learning outcomes and learning processes when students were studying two different treatments of instructional materials that contained either high-imagery or low-imagery visual representations. It was expected that high-imagery visual representations would offer learning advantages for students compared with low-imagery.

The data requirements of this study were examined and data collection techniques were reviewed for their appropriateness. The nature of learning in both assessment and process was discussed. It illustrated that an assessment of deep and meaningful learning requires a qualitative approach to examine differences between syntactic and functional knowledge. This was examined through data collected on learning outcomes. The post-tests were modelled on Mayer's research, examining verbatim, recall and transfer (problem solving) knowledge. This was used to assess whether either treatment had any effect on different types of knowledge.

To examine cognitive processes in learning and recall, retrospective reporting was used as an introspective analysis of cognitive processes, influenced by Richardson and Svensson. These reports were expected to inform why high-imagery representations might offer cognitive advantages compared to low-imagery visual representations.

As an extension of the research in Study 1 individual difference tests were used to further examine their value in predicting learning behaviour and assessing their usefulness in task- and context-specific learning episodes.

Background questionnaires used in Study 1 were also employed in Study 2 to examine whether learning outcomes or processes could be attributed to any other factor. This chapter concludes with a description of the methodology for Study 2 illustrating how the data collection techniques employed match the data requirements of the study.

Chapter 8 Study 2: Examining the Effect of High-imagery and Low-imagery Visual Representations on Performance and Learning Process

8.1 Introduction

This chapter describes Study 2, which examines the use of *high-imagery* compared with *low-imagery* visual representations for teaching a conceptually difficult area such as concurrency. It was predicted that the group studying the materials containing high-imagery visual representations would have higher performance as evident in post-tests and reduced cognitive overheads.

Participants were divided into two groups and asked to study the materials. They completed a post-test that was designed to qualitatively examine knowledge acquisition and to find out whether this was linked to the type of representation used in the study materials. After completing the post-test, participants completed post-learning introspective reports requiring them to record how they studied and remembered the instructional materials.

The individual difference tests, the Group Embedded Figures Test (GEFT), Cognitive Style Analysis (CSA), and the Learning Style Questionnaire (LSQ) were used to determine their value in predicting performance and learning process. Additionally the study aimed to further investigate their value in predicting behaviour in task- and context-specific learning episodes. Data was collected in the form of background questionnaires to identify whether any other factors were interacting with learning outcomes and learning processes.

The study illustrates three main effects: Imagers benefit most from visual representations, prior educational attainment is a good predictor of performance and functional knowledge is also a good predictor of performance. When the sample was adjusted to remove the imbalance of Verbalisers, high-imagery visual representations were shown to be useful. The high-imagery group had better performance on post-tests than the low-imagery group and they also incurred fewer cognitive overheads.

The results also indicated that using post-test scores as the main tool to assess learning improvements might be limited. The results suggest that an examination of learning processes is a more effective tool for examining student learning in a specific task and context. The results also showed that individual difference tests may not be suitable tools to examine specific episodes in learning as they may only offer generalised information. These results lead to the development of a model that illustrates the factors to be considered when adopting a practice-oriented research approach to learning in task- and context-specific episodes in learning.

8.2 Method

8.2.1 Participants

As in study 1, the participants were volunteers who were studying an Open University introductory computing course and an email was sent to students in regions within a 60-mile radius to ask for volunteers.

Students were initially asked to complete a background questionnaire. This demonstrated that students were typical of undergraduate computing students at the Open University.

This information was used to assign the participants to groups. Participants were randomly assigned to receive either high-imagery or low-imagery material.

Table 8.1 showing gender balance and age of groups

		Age Group					
		Under 24	***25-29***	***30-39***	***40-49***	***50-59***	***60-64***
Low-Imagery Instructional Materials	Female	0	1	2	2	0	0
	Male	2	1	2	0	1	1
	Total	**2**	**2**	**4**	**2**	**1**	**1**
High-Imagery Instructional Materials	Female	0	4	2	0	0	0
	Male	1	0	2	0	1	0
	Total	**1**	**4**	**4**	**0**	**1**	**0**

There were 12 students in the low-imagery group and 10 in the high-imagery group (there were originally 12 students in this group, but 2 dropped out). The groups were not gender balanced (see Table 8.1). The low-imagery group had an age range of 18-64 while the high-imagery group had an age range from 18-59. The most common age range in the low-imagery group was from 30-39 (*freq*=4) while the most common age ranges in the high-imagery group spanned 20-29 (*freq*=4) and 30-39 (*freq*=4).

8.2.2 Design

Participants completed the background questionnaire and returned it before the test to allow group assignment. This was controlled for on prior topic experience, as it was suspected that this might affect performance. The individual difference tests were administered on an individual basis before the study and recall activities began. The study and recall activities were administered on a group basis and were conducted under exam-like conditions. Two sessions were run over two weekends so that participants could choose which one they preferred to attend.

The following instruments, which were reported in chapter 5, were used in the experiment (see Table 8.2).

Table 8.2 Instruments used in the experiment

Instrument	**Procedure**	**Time Limit**
Background Questionnaire	Completed before study and recall activities	None
Learning Style Questionnaire	Completed before study and recall activities	None
Group Embedded Figures Test (GEFT) for Field Independence	Administered before study and recall activities on individual basis	12 minutes
Cognitive Styles Factor referenced tests (CSA) testing for Verbal-Imagery, Wholist-Analytic	Administered before study and recall activities on individual basis	None. Computer program records the time and calculates results
Study Activity	Administered in exam-like conditions on group basis	40 minutes
Recall Activity *Recall Post-test* *Transfer Post-test* *Verbatim post-test*	Administered in exam-like conditions on group basis	 20 minutes 30 minutes 2 minutes
Introspective reports	Administered after the study and recall activities in a relaxed but quiet atmosphere	None

The instructional materials covered introductory aspects of concurrency as an example of a difficult topic to teach in computing. There were two versions of the materials: both texts were informationally equivalent, but used different types of visual representations. The low-imagery version contained abstract diagrams, while the high-imagery version contained concrete representations that related to real world entities (see appendix I). Chapter 5 describes in detail the differences in the two types of representations.

The post-tests, based on Mayer's (1989) research, were designed to test for qualitative aspects of learning as opposed to quantitative aspects of learning. There were three parts to the post test: Verbatim, Recall, and Transfer. The verbatim test was a quick two-minute memory test and was included to be consistent with Mayer's original tests. The recall test asked students to write down everything they could remember, while the transfer test contained specific questions that examined the participants ability to apply knowledge. The verbatim questions, the recall concepts questions and transfer construct-reproduce questions were assessing syntactic knowledge while the remainder of the sections of the test were assessing functional knowledge. This was to enable distinctions between levels of learning displayed in each test.

When the post-test activity test was completed, participants were asked to write down the mental processes they used during the study activity and similarly those used during the recall activity. They were asked to report, from memory, how they had approached the process of learning, including what they were thinking, different tactics they may have used, and the types of things they did during this procedure. These instructions, for both learning and recall processes, were reinforced by printed instructions at the front of the retrospective post-learning questionnaires (see appendix J for an example of the instructions). This activity was not time-limited and was completed in a quiet relaxed atmosphere so that participants would be able to record as much as they could remember about their mental processes during both activities.

8.3 Results and Discussion

As there are a considerable number of results to report in this section, these will be interleaved with some discussion to guide the reader through this chapter. This will be followed up with a general discussion.

Two figures have been drawn to illustrate how the results interrelate. Figure 8.1 on page 264 illustrates the interrelationships between the factors that affect performance, investigated through learning outcomes. Figure 8.2 on page 270 illustrates the interrelationships between factors affecting performance, investigated through the cognitive processes. The figures are placed in the general discussion section as they are frequently referred to there to aid the explanation and interpretation of results. However, readers may benefit from looking at these figures during the reading of the results section.

8.3.1 Analysis of Performance

8.3.1.1 Does age or gender have an effect on performance?

The post-tests were scored using a pre-defined marking scheme (see Appendix N) and the scores were checked with an independent judge. Age and gender were initially examined to rule out any bias on these two factors. Correlations were performed between post-test scores and age and post-test scores and gender to assess whether there was any relationship between them. The results showed that there was no relationship between age and post-test scores (Pearson's r= .004, n=22, p=.847). Hence age and gender had no significant effect on the performance of participants in this study.

8.3.1.2 Does the use of high-imagery visual representations have an effect on performance?

The scores for verbatim, recall, and transfer tests and the overall score were compared for each group. A univariate analysis of variance was performed on the overall score in both groups simultaneously to assess whether there was a difference in the groups based on the treatment of the instructional materials they had studied. No significant difference was found in the overall score between groups *($F=.001$; $df=1, 20$; $p=0.977$).* The high-imagery group showed no better scores than the low-imagery group. This means that based on post-test scores there is no difference in performance between those students that received high-imagery or low-imagery materials.

8.3.1.3 Does the use of high-imagery visual representations have an effect on functional or syntactic knowledge?

The post-test scores were divided into the two part-scores of functional knowledge and syntactic knowledge. The syntactic score was the total of the *verbatim* score, the *recall concepts* score and the *transfer construct-reproduce* scores. The functional score was the total of the *recall explain, recall novel, transfer explain, transfer predict,* and *transfer construct-create* test scores. An analysis of variance was performed on both functional scores and syntactic scores to assess whether there were any differences as a result of using the high-imagery versus the low-imagery materials. There was no significant difference found between groups in functional knowledge *($F=.030$; $df=1,20$; $p=0.864$)* or syntactic knowledge *($F=.449$; $df=1,20$; $p=0.510$)* as a result of treatment.

These results mean that participants' overall score and their functional or syntactic score is not affected by using either high-imagery or low imagery materials. This is contrary to the expectation that high-imagery visual representations would improve performance for students. It was also expected that high-imagery visual representations might improve performance for computing students who are more likely to use syntactic knowledge, and similarly that high scores in functional knowledge would be indicative of expertise (Wiedenbeck, 1986). However, this was not borne out in these results.

8.3.1.4 What are the associations between other factors and the whole sample?

The high-imagery and low-imagery groups were so similar on overall score as to be considered as the same sample. Hence the sample as a whole was tested for associations between learning outcomes and other factors in the study, using Pearson's correlations. These are reported in the following sections.

8.3.1.4.1 What are the associations with functional and syntactic knowledge?

Tests for associations through correlations with learning outcome revealed some interesting results. Functional knowledge correlated very strongly with overall score, illustrated in Table 8.3. The more functional knowledge that students use, the greater their overall score.

Table 8.3 Pearson's Correlations showing relationships between functional knowledge, overall score and syntactic knowledge

	Functional Knowledge
Overall Post-Test Score	.910** n=22
Syntactic Knowledge	-.357 n=22

*(** indicates significance at the .001 level)*

There is also a non significant negative relationship between syntactic knowledge and functional knowledge. This may suggest that students who use more of one type of knowledge use less of another. Interestingly students scores in the verbatim tests and in the recall construct-reproduce tests significantly correlated indicating a relationship between these two scores (.548, n=22, p<0.01): students using a syntactic approach to the verbatim test were also using a syntactic approach in the recall test.

These results show that there is a significant relationship between functional knowledge and overall score. Hence having more functional knowledge is indicative of having a higher score. There is also a non-significant negative relationship between syntactic knowledge and functional knowledge. This may indicate that having more functional knowledge is associated with having less syntactic knowledge and that as expertise increases there is less use made of syntactic knowledge.

8.3.1.4.2 What are the associations with individual difference tests?

The individual difference tests were examined for associations with qualitative differences in knowledge such as syntactic and functional. A significant correlation was found with overall score in the CSA test on the Verbal/Imager dimension and with the Learning Style Questionnaire on the Theorist and Pragmatist dimensions (see Table 8.4).

Table 8.4 Pearson's correlation values for whole sample with individual difference scores

Cognitive Test	**Construct**	**Post-Test scores**				
		Syntactic Knowledge			**Functional Knowledge**	
		Verbatim %	**Recall: Concepts %**	**Recall: Novel Application %**	**Transfer: Predict %**	**Overall Score**
GEFT	*Field Independence*	-.015 n=22	.252 n=22	-.043 n=22	.189 n=22	.203 n=22
CSA	*Imager*	.414 n=22	.196 n=22	.254 n=22	.406 n=22	.444* n=.22
	Analytic	-.110 n=22	-.013 n=22	.325 n=22	.032 n=22	.190 n=22
	Activist	-.032 n=22	.320 n=22	-.003 n=22	.106 n=22	.201 n=22
LSQ	*Reflector*	-.018 n=22	-.249 n=22	-.403 n=22	.067 n=22	-.218 n=22
	Theorist	.488* n=22	.300 n=22	-.295 n=22	.305 n=22	.247 n=22
	Pragmatist	-.016 n=22	.552** n=22	-.088 n=22	.339 n=22	.395 n=22

(indicates significance at the 0.05 level and ** indicates significance at the 0.01 level)*

As can be seen from Table 8.4, no significant relationship was found between field independence and learning outcomes through any of the scores tested. In this study field independence did not prove useful in predicting learning outcomes.

The Verbal-Imager score from the CSA test had a significant correlation (at the 0.05 level) with the overall post-test score, which is a total score of all tests.

The higher a participant scores on the Imager scale the higher the overall score. In this study Riding's CSA test (1998) directly linked Imagers to post-test scores. Hence the higher participants scored on the Imager scale, the higher their overall post-test scores would be. In this study Imagers have benefited most from studying instructional materials containing visual representations. The Verbal/Imager scale in the CSA test has proved useful in predicting performance.

The reflector score from the LSQ test showed a non-significant negative relationship with the Recall Novel score (being able to recall information and apply it to novel circumstances). Although this score is non-significant it may suggest that the more reflective participants are the lower their scores will be on this test. Based on Honey and Mumford's (1992) description of reflectors preferring to wait and ponder before coming to any decision, it could be concluded that the time restricted test proved less favourable for reflectors.

Theorists have a significant correlation (at the 0.05 level) with verbatim scores. However, it is difficult to explain this result. The verbatim correlation is contradictory for theorists, where they would be expected to predict events based on theoretical knowledge, but not to practice rehearsal skills required for rote memorisation (Honey & Mumford, 1992).

Pragmatists have a significant correlation (at the 0.01 level, 2-tailed) with the Recall concept score. It could be that pragmatists adopt a simple approach to recalling memorised information.

These results can be summarised as follows:

- the CSA Imager dimension significantly correlated with functional knowledge (i.e. overall post-test score), indicating that Imagers make more use of functional knowledge and have high test scores
- the LSQ Pragmatist and Theorist dimensions significantly correlated with syntactic knowledge (i.e., recall concepts and verbatim scores, respectively), indicating that Pragmatists and Theorists use syntactic knowledge
- the Reflector dimension non-significantly negatively correlated with syntactic knowledge, which suggests that Reflectors make less use of syntactic knowledge

In conclusion, the only individual difference test that proved useful in predicting performance in the overall score is the verbal/imager scale on the Cognitive Styles Analysis test. While the Learning Style Questionnaire has some associations with syntactic knowledge these relationships appear to be contrary to the definitions of the dimensions on which they are based.

8.3.1.4.3 What are the associations with background information?

The most interesting variable that correlated with learning outcomes, and with other variables, was prior educational attainment. Participants' prior education attainment, as reported in their background questionnaire, was scored from 1, having no formal qualifications to 16, awarded for a post graduate degree (see Appendix K).

Correlations were performed to assess for associations with performance on post-test scores and other factors. Table 8.5 illustrates the correlations with prior educational attainment.

Table 8.5 Associations between prior educational attainment and other factors

	Overall Post-test Score	Functional Knowledge	Field-Independence	Pragmatist
Prior Educational Attainment	.468*	.427*	.550*	.447*

A sgnificant correlation was found between education level and overall post-test score (*Pearson's coefficient* =.468, *p*<.05).

The more highly educated participants were the greater their overall post-test score. Prior educational attainment also significantly correlates with functional knowledge, field independence and Pragmatist. Those that are well qualified have better functional knowledge. Those that are field independent and Pragmatists are also well qualified.

This means that prior knowledge is one of the strongest predictors of learning outcomes. This is confirmed in other studies, see Jonassen and Grawboski (1993) for a fuller review of this.

8.3.1.4.4 Do Imagers benefit from high-imagery visual representations?

As Imagers seemed to be benefiting from the visual representations most, the constitution of the low-imagery and high-imagery groups were examined to assess whether this was confounding any of the data. The low-imagery group appeared to have a higher constitution of Imagers and Bimodals (those who can benefit from both visual and verbal representations), than the high-imagery group (see Table 8.6).

Table 8.6 illustrating the constitution of both groups based on CSA groupings

Group	Low-imagery	High-imagery
Imagers	4	5
Bimodals	6	2
Verbalisers	2	3

The data was reanalysed removing the Verbalisers' data so that only those who might benefit from the visual representations were compared. An analysis of variance was performed to assess for differences between groups. The means between the group scores were different with the low-imagery group scoring 108.6 (*N*=10, *SD*=13.43) and the high-imagery group scoring 118.0 (*N* =7, *SD* =6.88), with an analysis of variance of *F*=2.863, *df*=2,15, *P*=.111. The analysis of variance is not statistically significant, however the sample sizes are small which makes trends harder to identify. Nevertheless the mean scores illustrate some difference in each group with the low-imagery group having a lower mean score than the high-imagery group.

This indicates that Verbalisers may not benefit from visual representations, particularly high-imagery representations, but that Imagers may benefit more from high-imagery representations.

The learning outcome data were also used to examine the literature claim that novices or low-ability students with fewer learning pre-requisites benefit more from high-imagery visual representations.

In this data set there were not enough low-ability students to compare. There were only three students in both groups that had no third level education. The rest of the students had some qualification at degree level and above, with four post-graduates in the low-imagery group and two post-graduates in the high-imagery group.

There appears to be some difference in the overall post-test scores between groups, when adjusted for Verbalisers, and this is indicative of low-imagery representations also being more cognitively challenging. The introspective reports were examined to investigate this theory.

8.3.2 Analysis of Learning Processes

The learning processes in both the study and recall activity were initially examined to gather a picture of what students were trying to do during both of these activities. This is reported in the next section.

8.3.2.1 What type of activities do students engage in during study and recall?

The participants in the high-imagery group reported using the visual representations and relating them to concrete experiences more frequently than those in the low-imagery group. Here are three examples.

> *Most of the material here I tended to relate to my experience from*

> *work reading it and the way I remember is by relating to similar situations or knowledge. I usually use the diagrams in particular for this....*
>
> *I try to relate key points to other similar information that I already know and understand. I try to build up a picture in my head.*
>
> *I was keeping an open mind approach in that if anything I read reminded me of something else that was relevant I'd make a note. This is often how I remember via association. One part made me think about probability [the example of] – TV & video.*

In comparison, the participants in the low-imagery group did not report that they were relating the information or diagrams to concrete experiences. However one participant did report an attempt at making a mental image or model for themselves, but seemed to have difficulty focussing on this.

> *If I could not make a mental diagram/connection/simile or other thoughts were in my mind too (gosh, this paper is white/what's that noise) then I read it again, trying to make the connection on each concept.*

When the participant's attempt at this failed she resorted to rote memorisation strategies.

> *Repeating the same phase over and over again helps. Picking out sentences and discarding waffly bits helps too.*

The participants in the low imagery-group appeared to struggle a bit more with the materials. This is evident when the two highest scoring participants in each group and the level and type of processes they reported are compared. This is illustrated in the following table, Table 8.7.

Table 8.7 illustrating the study processes of the top scoring participants in both the high-imagery and low-imagery groups

Processes reported of highest scoring high-imagery participant	**Processes reported of highest scoring low-imagery participant**
I think I tried to pick out the key points. I underline key sentences and try to remember these. I try to relate these key points to other similar information that I already know and understand. I try to build up a picture in my head.	I read the first couple of paragraphs a number of times because the information was not sinking in. It was unclear what points were being made. I then decided to move on to the next sections in the hope that things would be made clear, which they did. Some points were established and I underlined them in the text. Some of the sentences were longwinded and I did not take in much information. Interspersed with these were some very straightforward and to the point statements that stayed in my memory. The diagrams, whilst not the best I have seen, were not too difficult to follow, however some of the terminology in bold was hard to retain. Tried to remember a particular phrase by using the first letters of each word – but didn't stick I had a real sense that the beginning, middle and end were not fully expressed and whilst I had a sense of what I was learning, I had no clear flags to allow me to put the information into my mind. I do recall that the last page tried to pull the main objectives together but by this time I had lost interest and did not concentrate...

As can be seen from Table 8.7 the participant in the low-imagery group reported significantly more activity in trying to engage with the materials. The low-imagery participant scored the highest overall with 132. While she reports that the diagrams were not too difficult to follow, she later reports that she has nothing to attach this information to in her mind, i.e., being able to relate to other or concrete experiences or knowledge. In the high-imagery group the participant seems to have had more success in building a mental picture of the information. His score was 123 which is a little lower than the highest scoring low-imagery participant. However, the level of processes that the low-imagery participant reported indicates that she has had to engage in more mental activity in order to achieve this level of success.

Analysis of the recall processes revealed a similar situation as participants in the low-imagery group similarly found it more difficult to recall the information for the tests than the high-imagery group. Here are two examples.

> *Tried to remember the analogies and diagrams, it is difficult to marry which (diagrams etc) go with topics.*
>
> *Replayed what I had read in my mind. Did try to remember a diagram, but not very successfully.*

When the top two scoring participants' recall processes in each group are compared the effects of using high-imagery visual representations can be observed. Table 8.8 illustrates the recall processes of the top scoring participants in both groups.

Table 8.8 illustrating the recall processes of the top scoring participants in both the high-imagery and low-imagery groups

Processes reported of highest scoring high-imagery participant	***Processes reported of highest scoring low-imagery participant***
I try to relate the question to the picture in my head. I then try to answer the questions directly or by analysing the question together with what I already know.	For the first test I tried to picture pieces of text, but found it difficult to recall them. This is due to the absence of flags under which I would store the information. I found it easier to recall the diagrams than the text. For the second test (verbatim) I picked out sentences that were more long winded, because they reminded me of the style of the original text.

Table 8.8 illustrates that the low-imagery participant had more difficulty in recalling the information in the post-test. In particular this participant reports that she lacked anchors from which to draw the information. The participant reports finding the diagrams easier to remember than text, but it appears that the information lacks grounding in previous knowledge or concrete information that the student can relate to.

Participants in the high-imagery group appear to report using fewer cognitive processes than the low-imagery group. To examine this impression in more detail, the introspection reports were transcribed and analysed using standard protocol analysis procedures (Ericsson & Simon, 1984). Alberdi et al., (in press) and Gilhooly et al., (1999) were used as examples of protocol analysis in practice. This involved transcribing the participant's written report verbatim, and dividing the protocols into segments of actions, listing them one per line (a segment represents a basic action, idea or unit of thought), using an independent judge to assign the protocols to categories. This was performed separately for each of the two reports on study processes and recall processes.

An encoding scheme was generated that characterised the cognitive processes of the participants. This involved generating a label that described the behaviour indicated in each statement. The labels were intended to be mutually exclusive but in the event of a statement representing two different behaviours, two different labels were specified. Each label was given a description of the behaviour associated with it. In total 29 label categories were generated for the study processes and 9 were generated for the recall processes (Appendix L contains a list of the labelled categories and their descriptions).

While the encoding scheme was not checked by an independent researcher the categorisations were discussed with colleagues working in the area. In light of these comments the data was re-analysed several times and adjustments were made accordingly. The work in this analysis similarly reflects that reported by Green and Gilhooly (1996) and correspondingly ever hour of protocol material collected required approximately ten hours of analysis.

The protocol analyses for the study processes and recall processes are reported in the next two sections, respectively.

8.3.2.1 Do low-imagery visual representations incur cognitive overheads in study compared with high-imagery?

The low-imagery group on average reported 8.4 (*N*=12, *SD*=5.94) processes as opposed to the high-imagery group that reported 5.4 on average (*N*=10, *SD*=3.37) (see Table 8.9). An analysis of variance illustrated that the differences were not statistically significant,

F=2.02; df=1,20; P=0.171), however trends are more difficult to identify with small data sets. Nevertheless the mean scores revealed a trend in the low-imagery group to use more cognitive processes in learning.

Table 8.9 Mean scores of study processes and overall post-test scores of the low-imagery and high-imagery groups

Low-imagery Group		***High-imagery Group***	
Number of study processes reported	***Score on overall post-test***	***Number of study processes reported***	***Score on overall post-test***
10	117	11	118
0	98	8	123
11	118	3	115
1	93	8	125
6	111	2	109
3	121	7	108
11	89	0	57
22	130	3	73
11	108	5	123
10	91	7	120
11	99		
5	113		
Total = 101	Total = 1288	Total = 54	Total = 1071
Mean = 8.42	**Mean = 107.33**	**Mean = 5.4**	**Mean = 107.1**

The participant that had the highest overall post-test score was in the low-imagery group and reported 22 study processes whereas the participant who scored the highest in the high-imagery group reported only 8 study processes (see Table 8.9). The participant with

22 processes demonstrated a range of study strategies in use and changes of strategy during the learning process.

In accordance with the approach taken in the overall post-test scores, Verbalisers were removed from the data set to examine those who might be benefiting most from visual representations. The number of study processes is reported along with to the overall scores to show an interesting trend (see Table 8.10).

Table 8.10 Overall score and number of cognitive processes of Imagers and Bimodals

		Overall Score	Total number of cognitive processes
Low-imagery	*Mean*	108.6	**8.5**
	N	10	10
	SD	13.43	6.5
High-imagery	*Mean*	118.0	**6.8**
	N	7	7
	SD	6.88	2.7

Together, both sets of results from the study and recall analysis illustrate that the low-imagery group have a lower mean overall post-test score and a higher mean score on the number of overall processes reported. The high-imagery group appear to be more consistent in their results, indicative in the lower standard deviation. It appears that the low-imagery group is working harder at studying the materials and yet not scoring as well as the high-imagery group.

8.3.2.1.1 What is the relationship between the number of processes reported and deep and surface level approaches to study?

The encoded study processes for the whole sample and the sample minus the Verbalisers were grouped together based on surface or deep approaches to learning. These were informed by Richardson's (2000), Marton's (1976), and Svensson's (1977) perspective on deep and surface learning and were modelled on Somuncuncuoglu's (1999, p273-274) research.

Deep approaches to learning were characterised as students trying to understand the materials, identifying the underlying ideas and concepts, and relating information to other knowledge. Surface approaches to learning were characterised by memorisation strategies.

The number of times students reported using a deep approach and a surface approach to learning were correlated with the number of study processes they used in learning and the overall scores to establish whether or not a relationship existed between them.

The total number of learning processes correlated significantly with the overall post-test score (see Table 8.11). The results for the sample, minus the Verbaliser data, are reported in brackets. Deep approaches to study also correlated significantly with the overall score but surface approaches did not.

Table 8.11 Pearson's correlation coefficients between the study processes, deep approach processes and overall score.

	Number of Processes Reported	**Surface Approaches**	**Deep Approach Processes**
Overall Score	.437 * (.358) n=22	.234 (.334) n=22	.457* (.395) n=22
Number of Processes Reported		.808** (.809**) n=22	.870** (.846**) n=22

The sample minus the Verbaliser data is reported in brackets.

(denotes significance at the 0.05 level and ** denotes significance at the 0.001 level)*

This means that a student's overall score is related to the number of processes they use but more specifically to the number of deep approaches they use. Therefore a high scoring student is likely to be self-aware, in terms of their learning strategies, and also adopt a deep approach to learning, as characterised by Marton and Säljö (1976).

The participant that had the highest overall post-test score was in the low-imagery group and demonstrated a deep approach to study. However when these approaches were failing and the participant was experiencing difficulty, she reverted to rote memorisation strategies. This trend was echoed with other participants in the low-imagery group where they demonstrated a greater number of surface level approaches such as rehearsal and memorisation (see the first two lines of Table 8.12).

Table 8.12 Differences in study processes reported in each group.

Encoded Protocol	Encoded Protocol Description	No in Low-Imagery Instructional Materials Group	No in High-Imagery Instructional Materials Group
MEM	Participants reports using memorisation approaches to learning	8	3
RR	Participants rehearsing materials by re-read	9	3
UND	Participants reporting attempts to understand the materials	9	5
IMS	Participants identify their own metacognitive strategies for studying the material	11	6
IFS	Participants identify when a strategy is not working	6	1

Low-imagery participants also more frequently identified what study strategies they were using and when they had failed. Participants in the low-imagery group are either more naturally self-aware or else there are more traces of processes in short term memory as they were experiencing more difficulty processing the materials (Ericsson & Simon, 1984, p30).

8.3.2.1.2 *What is the relationship between the individual difference tests and study processes?*

None of the cognitive tests correlated with the number of study processes reported in the whole sample. However in the sample minus the Verbaliser data, the GEFT score showed a significant negative correlation with the number of processes reported. The following table (Table 8.13) illustrates the Pearson Correlation co-efficient for these instruments with the sample minus the Verbaliser data reported in brackets.

Table 8.13 Pearson correlation coefficients of number of study processes and the individual difference test scores

Cognitive Test	**Construct**	**Number of Study Processes**
GEFT (Group Embedded Figures Test)	Field Dependence/Independence	-.166 (-.519*)
CSA (Cognitive Styles Analysis Test)	Wholist-Analyst	.069 (0.41)
	Verbal-Imager	.208 (.005)
Honey and Munford Learning Style Questionnaire	Activist	.389 (.330)
	Reflector	-.214 (-.037)
	Theorist	.216 (.153)
	Pragmatists	.069 (-.102)

(The sample minus the Verbaliser data is reported in brackets)

This means that the more study processes a student has the more field dependent they are. This is not representative of the literature on field independence, which suggests that field independence students would have correlated positively both with the overall score and the number of processes used (Witkin et al., 1971). However the reverse trend is indicated in this study with a negative correlation with number of processes.

In this study none of the individual difference tests proved useful in predicting participants' learning processes.

8.3.2.1.3 What is the relationship between background factors and study processes?

The number of processes reported and the overall post-test score were not linked to pass level on the course, the number of previous courses studied at the OU, course grade (on the computing course studied), or the number of previous distinctions obtained on other OU courses, for either sample. Therefore the number of processes used in this learning activity is not linked to having studied previous OU courses or to previous OU course successes.

Prior education attainment did not correlate with the total number of processes reported, nor did it have any relationship with previous OU history or successes. Additionally educational attainment did not correlate with deep approaches to learning. These results are the same for the sample minus the Verbaliser data.

8.3.2.1.4 What are the findings for learning processes?

In conclusion, the following lists the findings in this section:

- Participants receiving the high-imagery materials tended to use fewer cognitive processes and thus were incurring fewer cognitive overheads when engaging with high-imagery visual representations. While this relationship was not statistically significant it is still suggestive of the value of high-imagery over low imagery visual representations.
- Participants adopting deep approaches to learning had significantly higher scores on the post-tests.

- Participants that report more processes were significantly more likely to use deep approaches to learning.
- Participants studying the low-imagery materials tended to use more surface level approaches to learning. This was identified by a visual comparison of the data in Table 8.12 rather than a test of statistical significance.
- No individual difference tests were significantly related to the number or type of learning processes used by students.

8.3.2.2 Do low-imagery visual representations incur cognitive overheads in recall compared with high-imagery?

The recall processes analysis was conducted in the same way as the study processes analysis. Overall there was a marginal difference found between groups in the number of recall processes reported by students in both samples. The low-imagery group had a mean of 35 recall processes and the high-imagery group had 30, similarly the sample minus the Verbaliser data had a mean of 29 and 25 recall processes, respectively.

However there were subtle differences in the strategies that participants reported using (see Table 8.14), where the sample minus the Verbaliser data is reported in brackets.

Table 8.14 Surface protocols in the recall introspection reports.

	Low-imagery	High-imagery
UTR (uses text to cue recall)	9 (7)	5 (4)
UDR (uses diagrams to cue recall)	6 (6)	4 (2)
NC (the cues used don't trigger full recall)	4 (4)	1 (0)
RMEM (uses rote memorisation strategies)	7 (4)	4 (3)
RUND (uses understanding to cue recall)	2 (2)	5 (5)
RRCE (relates to high-imagery experience)	3 (3)	4 (4)

(The sample minus the Verbaliser data is reported in brackets)

As Table 8.14 illustrates the low-imagery group focused more on using the text for recall and the diagrams than in the high-imagery group. Additionally the low-imagery group reported that the cues used (in the diagrams) were not triggering full recall.

Low-imagery participants also reported more use of recall through memorisation, than understanding, compared with the high-imagery group. However both groups similarly reported trying to relate questions to concrete experiences to cue recall. It would appear that the low-imagery students were having more difficulty in recalling information: they were using diagrams and text to help with recall although finding that the diagrams were not cueing association with information.

This could be explained by the low-imagery nature of the representation not triggering associations in memory to other information. While both groups were using similar kinds of strategies, the low-imagery group illustrated more activity in cueing from text and diagrams and resorting to memorised information. In comparison the high-imagery students' recall appeared to be more streamlined and deeper.

8.3.2.1.5 Are recall strategies and post-test scores related?

A correlation of the number of recall strategies reported with the overall post-test score did not prove significant. However the number of study processes correlated with the number of recall processes (Pearson's r= .473, n=22 p<.05), which does, as reported earlier, correlate with the overall score (Pearson's r =.364 in sample minus Verbaliser data).

This illustrates that recall processes are linked to learning processes and these in turn are linked to learning outcomes. So it appears that there is an indirect link between recall processes and learning outcomes.

8.3.2.1.6 Do high-imagery visual representations help the recall of information?

The high-imagery visual representations seem to provide participants with an intuitive recall cue, even if they considered them trivial during study. One participant reported,

> *Interestingly, [I] remembered the bit about TVs which I'd tried to dismiss as irrelevant!*

While another reported

> *The television example was very useful. I kept on relating things with the simple examples of the tele or the oven.*

The tangible nature of the diagrams in the high-imagery group provided triggers for students in both understanding and recalling the instructional material, where they could relate to high-imagery experiences. Conversely in the low-imagery group the highest scoring participant reported

> *I found it easier to recall the diagrams than text..... I tried to picture pieces of text, but I found it difficult to recall them. This is due to the absence of flags under which I would store the information.*

The low-imagery group appeared to have more difficult recalling information as they were lacking intuitive cues that provided easy recall. They tended to use text frequently for recall and reported that diagrams were not cueing full association with information. This is substantiated by the correlation between the use of diagrams and the lack of cues to full recall (Pearson's r= .483, n=22, p<.05), where the low-imagery group made the majority of these reports: 4 to 1 (and 4 to 0 in the sample minus the Verbaliser data).

In both the study and recall introspective reports those who were unable to articulate processes were among the lowest scoring of participants. There was one in each group. Those who are less self-aware appear to be inexperienced learners with underdeveloped study and recall skills.

8.3.2.1.7 **What is the relationship between the individual difference tests and recall processes?**

None of the cognitive tests correlated with the number of recall processes reported. The correlation coefficients are reported in Table 8.15.

Table 8.15 Pearson correlation coefficients of number of recall processes and the individual difference test scores

Cognitive Test	**Construct**	**Number of Recall Processes**
GEFT (Group Embedded Figures Test)	Field Dependence/Independence	.-.088 n=22
CSA (Cognitive Styles Analysis Test)	Wholist-Analyst	.124 n=22
	Verbal-Imager	.209 n=22
Honey and Munford Learning Style Questionnaire	Activist	.200 n=22
	Reflector	-.172 n=22
	Theorist	.052 n=22
	Pragmatists	.223 n=22

As can be seen from Table 8.15 there are no significant correlations. It would appear that none of the individual difference tests are useful in predicting recall processes.

8.3.2.1.8 *What is the relationship between background factors and recall processes?*

The number of recall processes reported were not linked to pass level on the course, the number of previous courses studied at the OU, course grade (or the computing course studied), or the number of previous distinctions obtained on other OU courses. Therefore the number of processes used in this recall activity is not linked to having studied previous OU courses or to previous OU course successes.

Prior education attainment did not correlate with the total number of recall processes reported either (Pearson's r= -.158, n=22, p=.482), nor was there any relationship with previous OU history or successes.

8.3.2.1.9 What are the findings for recall processes?

In conclusion, the following lists the findings in this section:

- Participants studying low-imagery materials appear to have more difficulty in recalling information
- The low-imagery group tend to use text and diagrams more to evoke recall
- The low-imagery diagrams were reported not to be triggering recall, particularly as it did not facilitate easy recall with associated information
- The high-imagery group had fuller and deeper recall
- The recall processes were indirectly linked with learning outcomes, via their direct correlation with study processes
- Less self-aware participants in both groups had the lowest post-test scores

8.4 General Discussion

There were three main factors affecting performance in this study. They were:

- Imager score
- functional knowledge score
- prior educational attainment

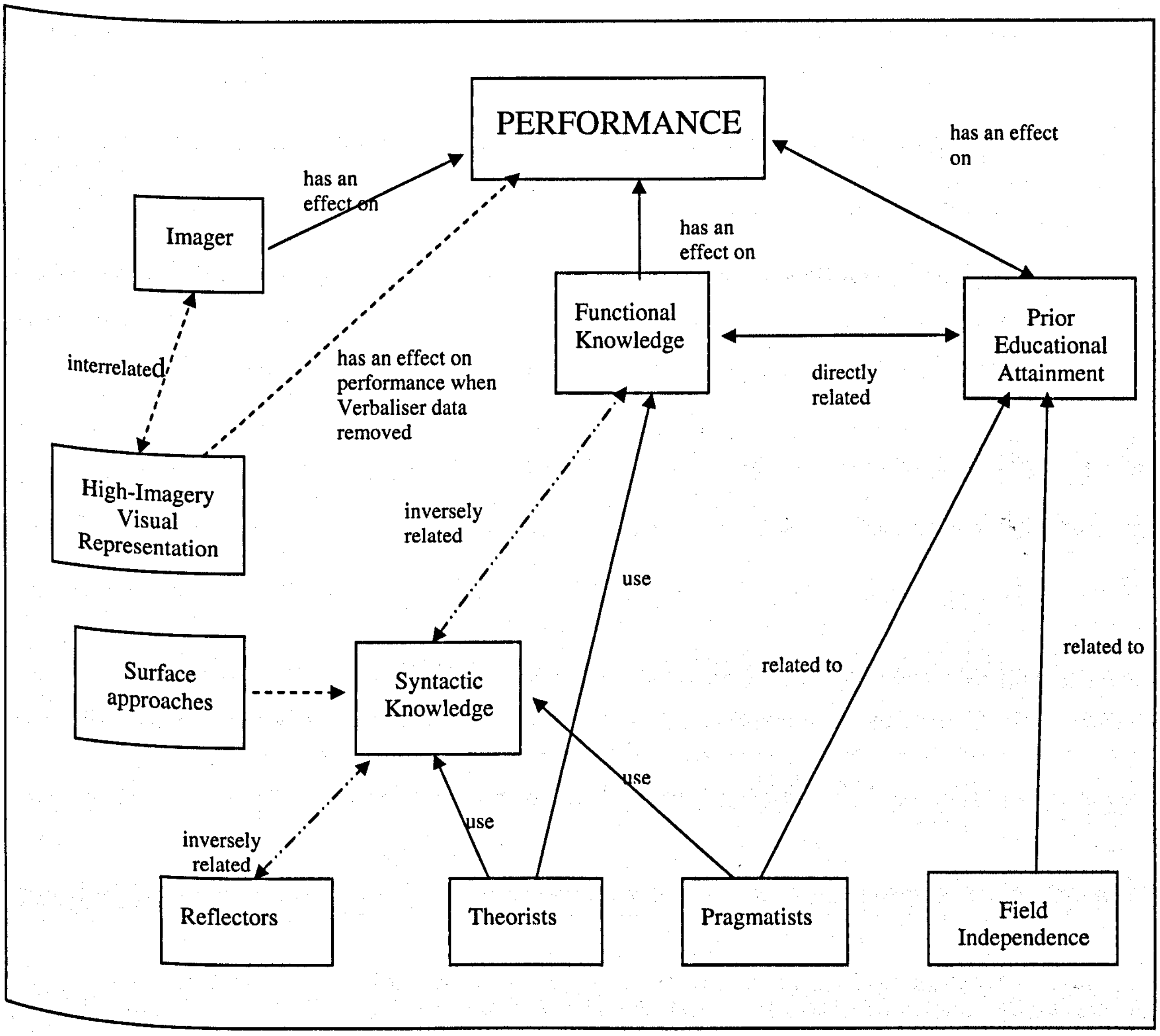


Figure 8.1 Model of the factors affecting performance from the post-test scores

These are illustrated in Figure 8.1. This means that students displaying imager traits benefited from visual representations and are likely to have better learning outcomes than Verbalisers do. Additionally, the more functional knowledge students use the more likely they are to have better learning outcomes. Furthermore, students who have achieved high levels of educational attainment are also more likely to achieve better learning outcomes. Prior educational attainment is also confirmed in this study as one of the strongest predictors of learning (Jonassen & Grabowski, 1993).

Functional knowledge and prior educational attainment are strongly linked, showing an effect between performance, prior educational attainment and functional knowledge. This is possibly a cyclical process where prior educational attainment affects functional knowledge, which affects performance that increases educational attainment.

High-imagery visual representations do appear to have value for students, although this was initially obscured by the imbalanced Verbaliser data between groups. When this was removed there was a difference in the means between the two groups' overall post-test scores.

The data was also obscured by the fact that the sample was not representative of novice learners that are also novice in a domain. The sample in Study 2 contained novices in concurrency who were not novice learners as some students had MSc's and one had a PhD. Thus these students were experienced learners that probably had refined study skills due to the educational experience that helped their performance. Students that were novices in studying probably had lower levels of performance due to their less refined study skills.

While an aim was to assess whether computing students benefited more from high-imagery visual representations, it was not possible in this study due to the highly qualified students represented in this sample. Unlike a traditional university, where undergraduate students are likely to be inexperienced in both subject and study, the students in this study were quite experienced, with most already having some third level education.

Mayer's (1991; 1992; 1989; 1997; 2000; 1990; 1994) work focussed on novices that were college students and he acknowledges that results were only salient for novice learners. Hence his students were likely to be novices in the domain as well as be novice learners. The participants in this group were novices in concurrency, but were not novice learners. This was evident from the information provided by students in the background questionnaire. Therefore more adept learners will have well developed study skills, or what Vermunt (1998) refers to as regulating strategies, that enable them to learn more effectively – even though they may be novices in a domain. This indicates that a distinction should be made between novices in a domain and novice learners, as their abilities are likely to be different due to this factor. The indications are that experienced learners do not benefit more substantially from high-imagery visual representations, although inexperienced learners may do.

Syntactic knowledge appears to be inversely related to functional knowledge and is not related to either prior educational attainment or performance. Hence individual cognitive development, evident through educational attainment, is a progressive move from syntactic knowledge to functional knowledge where performance and functional knowledge improve as students become more practised at learning. This supports Wiedenbeck's (1986) findings where that novice computer scientists use syntactic surface-level knowledge while experts use deep functional knowledge.

Interestingly there is a range of individual differences related to syntactic knowledge. As Figure 8.1 illustrates both Theorists and Pragmatists use syntactic knowledge although Theorists also demonstrated that they make some use of functional knowledge.

Pragmatists have better educational qualifications, but yet also demonstrate using syntactic knowledge. This could indicate that Pragmatists expected that a memory test was imminent after studying the materials and were cued to adopt a surface level syntactic approach (Scouller, 1998). Conversely, Reflectors make little use of syntactic knowledge but showed no relationship with any other factor. Field independence was also related to prior educational attainment and could indicate that Reflectors are more able to structure their own learning, leading to increased educational attainment.

The model of the interrelationships of factors illustrated in Figure 8.1 raises some issues, particularly in relation to individual difference tests. Two out of the four dimensions on the LSQ tests are related to syntactic knowledge. Does this mean than these dimensions only have value in predicting surface level knowledge, often evident in some assessment strategies? Or could the original basis for developing and testing this instrument lie with surface level outcomes? As none of the LSQ dimensions predicted performance or related to factors affecting performance, their value appears to be limited in practice-oriented task- and context-specific research in learning.

Field independence did not predict performance either, although it is related to prior educational attainment. The only test that proved useful in predicting performance was the Verbal/Imager dimension in the CSA test. This was clearly related to performance, however interrelationships with other factors were lacking. Despite the predictions that Imagers are more field dependent (Kirby, 1988) there was no such relationship found in this study.

Field independence similarly did not relate to performance or study processes, contradicting the expectations that science and engineering fields would have more field independents as structuring skills were inherent in these disciplines (Laurillard, 1978; Witkin et al., 1977). Richardson (1998b) also argued that field independence was not useful for understanding experiences or attainment in distance education. He concludes that "field independence is not an adequate measure of autonomy in learning and that it is not helpful in appreciating the experience of distance learning students or in predicting their academic attainment" (p247).

Similarly, Honey and Mumford's Learning Style Questionnaire was not particularly useful in predicting performance. The correlation found between Theorists and syntactic knowledge was unexpected, given they are reputed to hypothesise on 'what if' situations, although they did display links with functional knowledge (Honey & Mumford, 1992). The negative correlation of syntactic knowledge with Reflectors illustrates that they may be using more functional knowledge, however no relationship with other factors was evident. The Pragmatist result is interesting as it correlates with functional knowledge and prior educational attainment. It could be that Pragmatists adopt what they consider to be the most pragmatic approach for the task and in this case they expected that a memory test was eminent after studying the materials. The results using the LSQ were patchy and could not be considered reliable as predictors of performance.

None of the individual difference tests proved useful in predicting either study processes or recall processes. They appear to have limited value in predicting an approach to learning that is episodic. It may be that individual differences provide more generalisable information that is not suitable for examining task- and context-specific learning episodes.

A slightly perturbing implication of the strong relationship with Imagers and representations type is that Verbalisers could be disadvantaged in a very visual version of instructional materials. Riding and Sadler-Smith (1992) argue that although Imagers do benefit more from visual representations it is not to the detriment of Verbalisers. They argue that all can benefit from instructional materials containing concrete diagrams. This perspective is supported by Holliday (1976) and Winn (1982; 1981; 1982).

However Cox (1999), Oberlander et al. (1999) and Stenning et al. (1995) argue that these kinds of differences should be taken into account when choosing instruction as they can affect learners that are less visually and spatially aware. An as yet unanswered question is whether students should be encouraged to follow their modality preferences or be encouraged to use visual representations (Messick, 1984; Miller, 1991; Pask & Scott, 1973; Stenning et al., 1995).

Since increased performance is linked with an increased number of alternative memory codes available for an item, having more than one type of representation should be helpful to learners (Mayer & Anderson, 1991; Paivio, 1971, 1978, 1979, 1986). It may be that visual representations need to be improved so that those who do prefer to use them can benefit from them while providing enough coherent supporting expository text so that Imagers can benefit from them too.

If there are qualitative differences in learning outcomes, then it suggests that there are qualitative differences in learning processes (Marton & Säljö, 1976). This premise was substantiated by the qualitative analysis of the processes in introspective reports and participant comments. Figure 8.2 provides a model of how the learning and recall processes interrelate.

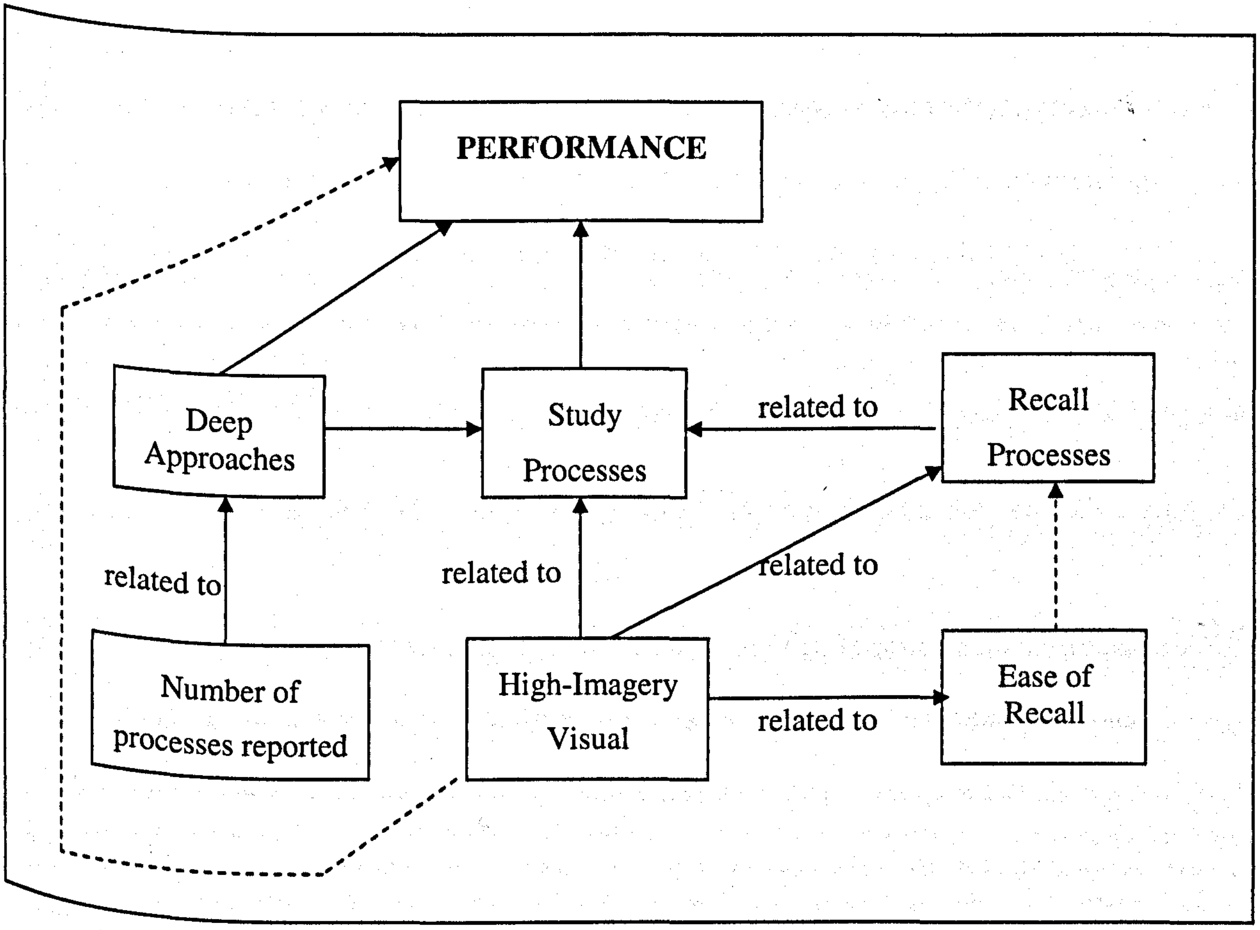


Figure 8.2 Model of factors affecting performance from the cognitive processes

As can be seen in Figure 8.2, the number of processes reported, ease of recall, and recall processes, and high-imagery representations have indirect relationships with performance: they all contribute in some way to the study and recall processes that affect performance.

It appears that low-imagery visual representations present students with more cognitive overheads than their high-imagery counterparts. They reported using more processes and yet had lower mean post-test scores. Thus low-imagery students were working harder at studying the materials and yet not scoring as highly.

The analysis also illustrated that students who used deep approaches to learning also reported using a greater number of processes overall, and these were significantly related to performance. So those students that used deep approaches to study are likely to have a large repertoire of strategies to choose from, which enable them to perform better in a post-test, illustrated in Figure 8.2.

However it would be expected that deep approaches to learning would correlate with previous educational attainment as students adopting a more meaningful approach would be capable of producing higher grades (Marton & Säljö, 1976). This was not confirmed in this study. A reasonable conclusion is that not all school and university examinations test for deep knowledge and students adapt their style to what they perceive as the assessment procedure (Scouller, 1998). This perspective was corroborated by one student who reported that having knowledge of the test before studying the materials would have enabled a more effective tuning of his study practices. As the nature of the post-test was blind to participants it could be that 'better' students adopt a meaningful approach when knowledge of the assessment procedure is unavailable.

Analysis of the recall data indicated that students in the low-imagery group were trying to use recall diagrams as cues to other information, but this strategy proved ineffective. As the low-imagery diagrams were abstract they may have offered little opportunity to develop referential links to other information. Conversely some students in the high-imagery group reported that concrete diagrams had enabled them to remember information intuitively as they were able to relate abstract examples to concrete experiences in everyday life.

Scanlon (1998) reports that novice physicists had difficult making associations between graphs and information, causing cognitive overheads. As Scanlon's graphs were low-imagery representations this might explain why students experienced difficulty. It may also be attributed to the fact that these students were school children aged 12-16 and likely had novice learning skills Theoretically low-imagery visual representations do not easily support the construction of associative connections between visual and verbal representations (Paivio, 1971, 1978, 1979, 1986).

Using high-imagery visual representations can trigger more effective associations to previous experiences and knowledge in the verbal representation system where it promotes a more meaningful set for the learner (Ausubel, 1963; Taraban, 1993). A visual representation is only useful for those who understand the computational processes of the diagram (Larkin & Simon, 1987). Knowledge of how to interpret a diagram, particularly a low-imagery visual representation, cannot be assumed.

While it is desirable for novices in a domain to capitalise on abstract representations for conciseness as part of the evolutionary process to expertise, it may require some intermediary visual representations or specific teaching of how to interpret and use them. This may be especially important in easing the burden of learning conceptually difficult areas (de Jong & Ferguson-Hessler, 1991; Scanlon, 1998; Scanlon & O'Shea, 1988). Based on the results of this study, the type of visual representation used may also depend on the level of sophistication of the learners' study skills, where those with less educational experience will need more augmentation of the representation.

The results show that a well-educated student may well have developed enough strategies to compensate for underlying individual traits and be able to adapt strategies to task and context. Therefore the effects of a particular trait may go unnoticed in more quantitative learning outcome assessment approaches. In Study 2 the assessment of learning outcomes did not initially make differences apparent. However the introspective analysis of learning processes found that students studying low-imagery visual representations were incurring cognitive overheads.

This presents researchers with a problem. On the one hand developing learners as rounded individuals able to cope with learning in a range of tasks and contexts is a primary aim. On the other hand information is required to enable development of improved instructional materials that are as congenial as possible for students. If learning outcomes is the assessment used to judge learning then it is not possible to assess whether strategies are inter-playing with a more persistent individual trait or factor.

It may be more productive to include some assessment of students' processes in order to investigate the cognitive overheads or economies that are incurred. It is argued here that researching learning outcomes through exam-type assessment may not appropriately measure the success of instructional improvements in episodes of learning. There may be other factors affecting behaviour, not least of all cueing from the test itself (Marton & Säljö, 1984; Scouller, 1998).

The approach that Marton and Säljö (1976; 1984) use to investigate approaches to learning through introspective reporting seems to enable an examination of task- and context-specific episodes in learning. As Laurillard (1993; 1978) purports this may be more useful for the practising educator who is interested in the improvements realisable in actual instruction for learners. The problem with this approach is scalability as the data collection procedure is only practical for small numbers. This has led to the kind of approaches that Entwistle (1981; 1988) and Lawless and Richardson (in press) have taken in their use of inventories that assess students' approaches to study as opposed to defining their style of learning or information processing.

In this study, learning processes were observed as strategies that regulated other factors such as the Verbal/Imager trait. Information processing style and strategy are different, where style has some psychological basis and strategies are ways that learners have developed to cope with tasks (Riding, 1997). The research from this study shows that there is a difference between a dominant style, in this case Imager, and the strategies used, evident in the learning processes. This perspective also reflects Vermunt's (1998) model where he refers to these processes as regulating strategies. It appears that a different model is required to reflect aspects of learning that are pertinent to a practice orientated examination of task- and context-specific episodes in learning.

A question in this thesis was whether individual difference tests were appropriate tools to examine issues in task- and context-specific episodes in learning. The use of individual difference tests to predict performance or process in a learning episode raises validity issues where a 'practice-oriented' approach is adopted (Laurillard, 1978). None of the tests were useful in predicting preference for instructional materials in Study 1. However, the Verbal/Imager dimension in the CSA tests was useful in predicting performance in Study 2, although it did not show relationships with other factors that might have been expected. Additionally the other tests offered little value in predicting outcomes or learning processes.

One of the main benefits of this study is the triangulation approach adopted to understanding learning outcomes and learning processes. This has provided complementary information from a range of perspectives that strengthen the results. Most importantly it provided information about learning and recall activities associated with studying visual representations (Marton & Säljö, 1976). The results show that high-imagery representations offer students less cognitively challenging representations that can have an impact on learning. One limitation of this study was that it did not record the response time in either the study activity or the recall activity. In a study comparing the effects between using animations, static graphics and no graphics, de Jong (1998) found a major effect, evident in response times. Recording response time in this study might have provided some valuable information into cognitive overheads incurred while studying low-imagery representations.

The models of the results illustrate the complex nature of learning and the multiplicity of factors that affect it. The results of this study have led to the development of a model that encompasses these factors in episodes of student learning. The following section reviews this model.

8.5 Development of a Model of Learning

A practice-oriented model has been developed that considers episodes of student learning. This is based on both the literature reviewed in chapters 3 and 4 and the research results of this thesis. Studies 1 and 2 have shown that there are issues associated with using individual difference tests in practice-oriented research.

In the first study none of the individual difference tests proved useful in predicting preference for representation. In the second study only the Verbal/Imager dimension proved useful in predicting performance, while none of the tests proved useful in predicing learning processes. One concern is the general versus specific use of these tools to examine learning. Messick (1984) argues that style is a measure of a general orientation to tasks and situations and that a strategy is attuned to particular tasks and situations. If these strategies have subsequently been interpreted as a style of learning then a learning style inventory only reflects these general tendencies (see chapter 3). A generalised inventory cannot then take account of particular tasks and situations in a given episode of learning (Laurillard, 1978).

Task and context appear to affect an individual's approach to learning (Laurillard, 1978). Marton and Säljö (1984) noted the 'technification' phenomena where students' study approaches in a task mirrored the task requirement. Students were more concerned about being able to answer questions appropriately as opposed to using a deep approach to learning. Therefore the approach to learning in this instance was cued by what was perceived as the assessment strategy which in turn cued the approach to the task. This is also documented by Scouller (1998). So task and context must have an impact on how students will approach a particular aspect of study at a micro level in order to meet the goals of the learning.

There appears to be a difference between investigating a student's general approach to study in a programme and a student's approach to a specific task. For those researching the improvement of instructional materials experimentally and empirically, a different approach is required to enable a close inspection of students' learning in particular contexts in an episode of learning.

At this point it is useful to distinguish between the goals of different inventories and approaches to investigating factors in student learning. At one level there is a desire at a macro level to have an overarching view of students' general orientations to a programme or course of study. Individual differences inventories try to achieve this goal as it would be impossible to conduct scalable research that can assess students' general orientations and approaches to study using micro level tools such as introspective analysis, interviewing, and teach-back.

At the other extreme, investigating students' approaches to episodes of study requires a finer grained analysis in order to investigate factors such as instructional improvement through experimentation. At this level task and context interplay and need to be taken into consideration. For these kinds of investigations generalisable inventories may not be suitable, but techniques such as introspective reporting can inform researchers about the kinds of cognitive activities students are performing. There is of course some area in the middle where a fine grained analysis is required for investigating large numbers, requiring some kind of a crossover between both of these situations and techniques. For example, the following Figure 8.3 illustrates the case in point.

Generalised learning approaches	Specific learning approaches
Institutional based research	Practice-oriented research
Macro level research ←	→ **Micro level research**
Internal processing	External stimulus-based
Assimilating strategies	Processing strategies
Persistent traits/tendencies	Traits mediated by regulating strategies
Cognition/personality centred approach	Activity centred approach

Figure 8.3 Continuum of approaches to investigating different situations in learning

It is important to establish what the goal of the investigation is in order to select an appropriate assessment tool. For example, trying to assess micro level episodes of learning with tools for assessing general approaches could provide misleading results as task and context have an impact on learning (Laurillard, 1978; Marton & Säljö, 1984).

Coupled with the concern of the generalisability versus specificity of an assessment procedure there are regulating strategies that interplay. This was evident in Study 2 where students' processes were shown to compensate when instructional materials were less congenial for learners. This makes investigation into micro level learning factors difficult. If regulating strategies are those which learners use to compensate for more ingrained traits, then examining any change in learning through exam-like post-tests will not expose the level of regulating strategies (i.e. compensation) that students are using. Arguably this kind of analysis is better performed using introspective reports and protocol analysis. Additionally the regulating strategies illustrate that students do compensate for either ingrained traits or less congenial instructional materials.

There is also another factor that needs to be considered and that is the difference between inexperienced learners and novice learners in a domain: the two are not the same. As prior educational experience was a significant predictor of performance that related to functional knowledge this suggests that those who succeed best are those with more extensive and elaborate 'regulating' strategies for dealing with the task of learning. This concept has been informed by Vermunt's (1998, p153) research and this study confirms that students do use strategies to regulate their learning. Curry's model (reviewed in chapter 3) has some parallel themes with Vermunt's model. However Vermunt's model serves more as an overarching construct that appears to straddle all three layers in Curry's (1983) model (Richardson, 2000).

The model illustrated in Figure 8.4 is an extension of these ideas. This extended model also includes the factors discussed in this section such as prior educational attainment, task and context and assessment strategy. This model is aimed as describing the interrelating factors in a task- and context-specific episode of learning. However it should be noted that this model is for self-instruction only.

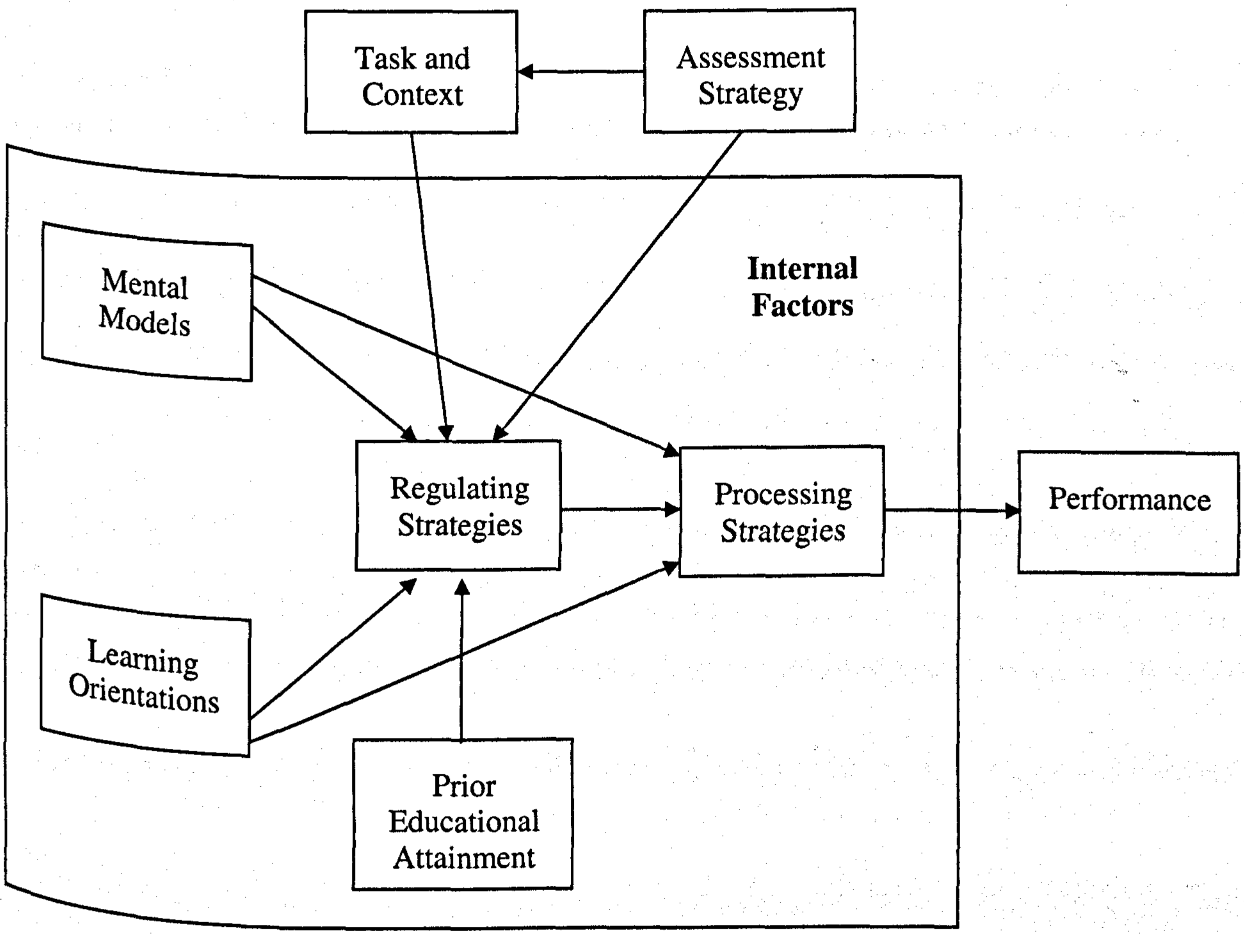


Figure 8.4 Approaches to Episodic Learning

Figure 8.4 illustrates the internal and external factors affecting an episode of learning in a specific task and context in a self-instruction learning situation. The added entities to Vermunt's model are *prior educational attainment*, *task and context* and *assessment strategy*. Vermunt defines learning orientations and mental models as follows:

> Learning orientations refer to the whole domain of personal goals, intentions, motives, expectations, attitudes, worries and doubts of students in doing courses or studies (Vermunt, 1998, p151).

> A mental model of learning is viewed here as a coherent whole of learning conceptions: conceptions and misconceptions about learning processes. This concerns conceptions of learning and thinking activities, conceptions about oneself as a learner, conceptions of learning objectives and learning tasks, conceptions and studying in general and conceptions of the task division between oneself and others in learning processes (Vermunt, 1998, p151).

Regulating strategies are described as cognitive activities that lead to learning indirectly. They plan the process and monitor the progress of learning, diagnosing and regulating any difficulties that occur during learning. These activities were observed in Study 2 in the introspective analysis on learning and recall. Accomplished learners had a large range of strategies to choose from and when one failed they would resort to using another one. In addition to the relationship shown in the figure, one would expect prior educational attainment to be correlated with student's learning models and mental models.

The regulating strategies relate to processing strategies: processing strategies are summarized as *used to process learning contents and to attain their learning goals by doing so*. This is more broadly interpreted in this model to mean interacting with the external world in the processing of information and learning contents in order to achieve the specified goal of learning. Curry (1983) refers to processing strategies as information processing style where this is similarly described as an entity that assimilates information from external stimuli.

The addition of *task and context* as an entity to this model has been inspired by the practice-oriented approach used in this study. This illustrates that using individual difference tests and learning outcomes may be too general to be useful for specific learning episode examination. This perspective has also been influenced by the work of Laurillard (1993; 1997; 1978), Marton and Säljö (1976; 1984) and Richardson (2000), who adopt encompassing approaches to the assessment of student learning.

The addition of *assessment strategy* as an entity is influenced by Marton and Säljö (1976; 1984) and Scouller (1998) who found that the assessment strategy was powerful in cueing students to adopt a particular strategy to learning. There was also a limited indication in Study 2 that this might have been a factor affecting pragmatists' use of syntactic knowledge especially given they were highly qualified students.

The inclusion of *prior educational attainment* as an entity was due to its relationship with performance and functional knowledge, illustrated in this study. It was also related to other factors and appeared to be a good predictor of success. All of the components are combined in Figure 8.4 to illustrate an individual's approach to an episode of learning in a task- and context-specific situation.

The model has been developed to illustrate some of the findings of this research and how they co-exist with current research. It also intended to help other researchers understand the multiplicity of issues that need to be considered when adopting a practice-oriented approach to researching an episode of learning that is task- and context-specific.

8.6 Summary

This study examined the use of *high-imagery* compared with *low-imagery* visual representations in teaching the conceptually difficult area of concurrency in computing. Students were divided into two groups and given materials that differed in the reality of the visual representations, where both sets of instructional materials were informationally equivalent.

Participants completed post-tests after studying the materials to assess whether performance was dependent upon the type of visual representation. Participants also completed post-learning introspective reports where they recorded the cognitive processes they used in both the study and recall activities.

The individual differences tests GEFT, CSA and LSQ were also used to confirm their value in predicting performance and learning process. Data was collected in the form of background questionnaires to identify whether any other factors were inter-playing with study, recall and learning outcomes.

The post-test was designed to examine qualitative aspects of learning such as syntactic and functional knowledge. This was scored against a pre-defined marking scheme and standardised. The introspective reports were analysed using standard protocol analysis and grouped into processes by an independent judge.

The results showed there were three main factors affecting learning outcomes. These were the Imager dimension of CSA, previous educational attainment, and functional knowledge. The sample was adjusted to remove the Verbaliser data and reanalysis showed that the high-imagery group had a higher mean score than the low-imagery group. This was further substantiated by the protocol analysis in the introspective reports that showed the high-imagery group were incurring less cognitive overheads and performing better than the low-imagery group. The low-imagery group were incurring cognitive overheads (i.e. doing more processing) and yet had a lower post-test score. Qualitative analysis of the protocols showed that participants in the low-imagery group were grappling with both learning and recalling information. Participants reported not having high-imagery cues from which to associate the diagrams with knowledge, which later affected their recall.

In this study the Verbal/Imagery dimension in the CSA test was useful in predicating performance. The Verbal/Imagery scores correlated with three post-test scores. However the other individual difference tests GEFT and LSQ produced patchy and unreliable results. In this study these two tests did not appear to be valuable.

The use of the individual difference tests in both studies indicates that they may be unsuitable for practice-oriented research that examines task- and context-specific episodes of learning.

Based on the results of this study, Vermunt and Curry's model of learning, and the literature review in chapter 3 and 4, a model was developed to illustrate factors that need to be considered when adopting a practice-oriented approach to learning that examines task- and context-specific episodes of learning.

The results also indicate that using more quantitative approaches to assessing learning outcomes to judge the value of an educational development may be limited. As Study 2 illustrates such an examination may have initially glossed over effects due to the use of high-imagery visual representations, which were illuminated through analysis of the introspective data. This effect could also have been obscured by the presence of experienced learners that are novices in a domain, and thus assumed to be novice learners. Thus a deeper approach is argued for on the strength of this research as a means of more carefully examining factors affecting a student's approach to an episode in learning.

The strength of this study has been the triangulation approach used to understanding the factors that affect performance and process in learning. This had led to a thorough analysis of the data showing that high-imagery visual representations are useful. It has also led to the development of a model that illustrates how the results of this research integrates with current research and what factors should be considered in assessing approaches to episodes of learning.

Chapter 9 Conclusion

9.1 Introduction

This final chapter summarises the main achievements of the research in this thesis. It describes the implications that this has for educational technology, computer science and research into student learning. It acknowledges the limitations of the research and outlines areas fruitful for future investigation.

9.2 Main Findings

The research described in this thesis is concerned with the teaching of difficult concepts to students studying computer science at a distance. The thesis explores students' perceptions and preferences for representation in instructional materials and examines the effects of using high- and low-imagery visual representations in learning. There have been a significant number of achievements in this research:

- The finding that visual representations have positive influences on students
- The finding that high-imagery visual representations have a positive impact on learning
- The finding that prior educational attainment is a factor affecting performance
- The finding that functional knowledge is a factor affecting performance
- The confirmation that the Verbal/Imager dimension in the Cognitive style Analysis test was useful as a predictor of performance
- The finding that the Group Embedded Figures Test was not useful in predicting preference, performance or learning process

- The finding that the Learning Style Questionnaire was not useful in predicting preference, performance or learning process
- The identification of dual processing as a theoretical basis for understanding the variation in research results in visual representations
- The development of guidelines for information representation in instructional materials
- The comparison and contrast of expert-novice differences through academics and students in representation preference and perception
- The detection of academics' lack of reflective practices in representation design
- Development of a model to illustrate factors affecting performance in task- and context-specific episodes in learning
- A critique of the individual difference literature
- A critique of the visual representation literature

The strength of this research has been the triangulation approach used to understanding the influences and effects of visual representations in learning for distance education students studying computer science. This has led to a thorough and in-depth analysis of the issues identified in this thesis from a range of complementary perspectives and presents a number of important findings.

The research has shown that visual representations are powerful tools for cueing students to perceive instructional materials as more engaging and easier to study. This is an important finding for educational technology as well as computer science.

The challenge of teaching abstract concepts also exists in physics and mathematics and it is likely that the value of using visual representations will apply to these domains also. At present there is no reason to believe that these results will not generalise to other domains that have challenges in teaching abstract topics. However, it may not generalise to some arts topics, where visual representations are used as discussion tools as opposed to aids in helping students understand abstract concepts.

The effect of visual representations on learning was explored by comparing the effects of high-imagery versus low-imagery visual representations on performance and process. High-imagery visual representations are useful for students studying conceptually challenging areas in computing. The nature of the comprehensive data approach has shown some of the interrelating issues in learning, evident in this study as the Imager cognitive style, previous educational attainment, and functional knowledge.

The research has also lead to the judgement that the value of individual difference tests may be limited by the nature of the general information they provide. Using individual difference tests to assess specific episodes in learning may be inappropriate. The examination of learning has lead to the development of a model that illustrates factors affecting performance in task- and context-specific episodes in learning. The culmination of these findings has important implications for educational technology, computer science, and research methodologies.

9.3 Implications for Educational Technology

One of the main implications of this research for educational technology is that visual representations are powerful tools for engaging students. Students perceive materials containing visual representations as more engaging and easier to study and subsequently students are more likely to be receptive to the information presented.

Visual representations have the ability to enhance learning by presenting difficult concepts in a way that is accessible for learners. However, in order for students to benefit from visual representations, they must be able to understand them and then relate them to both the expository text in the materials and to other information. Ausubel (1963) argues that unless the representation is meaningful for the learner they resort to rote memorisation strategies that form arbitrary internal links, making information retrieval less effective. This requires students to develop associative and referential links (Paivio, 1979), which Scanlon (1998) argues is important for co-ordinating and understanding all the information presented.

The implications of this are three fold. First, using visual representations to teach inexperienced learners requires intuitive representations where students can relate the information to real world situations, as in high-imagery visual representations. Second, students need to be taught how to interpret more abstract visual representations to be able to understand them. Third, abstract visual representations need to have consistent and codified depictions where students can progressively learn to use them effectively for learning.

This research also has value in informing us on how visual representations may have use in media other than print. Given that it is more difficult to read text on screen and that the culture of the web reflects quick and easy access to information, visual representations may have value in delivering information more accessibly in these circumstances.

Furthermore, the introduction of other platforms such as hand-held devices and interactive digital television will also require guidance on how to use visual representations effectively, given the physical constraints of the devices to display information. This trend is currently reflected in the European Union funding projects researching information accessibility, particularly in electronic media (European Commission, 2002).

The research in this thesis also draws a distinction between novices in a domain and novice learners. This was evident from the information provided by students in the background questionnaire. There was a direct relationship between performance and previous educational attainment in Study 2, even though all of the students were novices in the domain of concurrency. Novices in a domain that are experienced learners are likely to have study skills or 'regulating strategies' that enable them to compensate for instructional materials containing representations that less congenial to their personal preferences. In comparison, novice learners that are also novices in a domain may struggle more in these circumstances. Their study skills or 'regulating strategies' are less developed and they likely to be struggling to developing both knowledge in the domain and in approaches to study. This may be an important consideration when evaluating educational innovations.

The research in this thesis has important implications for the design and evaluation of visual representations. It has shown that visual representations are powerful tools for positively influencing students to perceive information as easier and more inviting. These results may have implications for how visual representations are used in other media. However, when evaluating innovations with visual representations it is important to distinguish between novices in a domain and novices learners, as their requirements are likely to be different. In short, this research makes a contribution to the body of knowledge on practice and understanding of teaching in particular subject areas, where the example in this thesis is computing.

9.4 Implications for Computer Science

This research makes a significant contribution to computer science in understanding the effects and appropriate use of visual representations in teaching computer science. It has shown that visual representations are powerful tools not to be underestimated in engaging students in learning this topic. Using visual representations effectively can offer a means to ameliorate the burden of learning abstract concepts and understanding invisible processes.

As novices rely on concrete information, using visual representations may assist in developing mental models to aid reasoning about the behaviour of computing processes (Wiedenbeck, 1986). However their use with novices needs to be tempered with representations that students can readily understand and relate to the real world. This is necessary to offer students intuitive tools that enable them to make meaningful connections with other knowledge, while also supporting more effective retrieval of information.

This suggests the importance of further research into the appropriate use and circumstances in which visual representations are useful in computing. Other research is currently investigating the value of different representations for novice and expert programmers in understanding and debugging programs (Du Boulay et al., 2001). It is examining visual representations in computing and how individuals integrate multiple representations to aid program comprehension. They hypothesise that differences in the level of imagery in a representation can be a factor affecting its usefulness. They are also investigating visual/verbal preference to assess its affect on individuals' ability to translate between representations.

9.5 Implications for Student Learning Research

The research in this thesis offers significant contributions to practice-oriented research in episodes in student learning. There are two main contributions: knowledge of the general versus the specific nature of individual differences tests and the kind of data they offer researchers, and the development of a model that describes factors in task- and context-specific episodes in learning.

The first contribution to student learning research stems from the investigation into the value of the individual difference tests as tools for investigating student learning. This thesis provides an in-depth critique of the literature on their theoretical basis, validity and consistency with other tests. The literature review highlights a number of points to be considered in their use.

First, some of the tools have been developed in context free artificial situations that were not task dependent. These tools can offer general information about tendencies but may not be specific enough to be valuable for examining episodes of learning.

Second, there is no clear consensus on the similarities and differences between the tests and how these results relate. Chapter 3 used Curry's (1983) model to review individual difference constructs and their tests in order to offer some coherence for readers.

Third, the theoretical basis for the tests differ, ranging from a cognitive basis to an activity basis. This means that the goal of the test and the information that it provides may be different and interpretations may vary. This review has been valuable in articulating issues that researchers need to consider when using them.

This critique was further enhanced with results from this thesis. The results from studies 1 and 2 showed that the three individual difference tests used across two different studies did not consistently provide specific information relevant to the investigation of task and context dependent episodes in learning. Both the GEFT and LSQ appeared to offer more general information. The field independence construct appeared to offer information about general tendencies in task structuring that were not relevant to the specificity of this examination. Similarly the learning style test appeared to offer general information about styles of study, also not relevant in the specific nature of this examination.

However, the Imager dimension in the CSA test proved useful. This was largely because it was measuring the visual/verbal information processing trait that matched the nature of this task, which was students' ability to assimilate information in different visual representations with text. The literature critique and results of this analysis contributes to a growing body of knowledge on the appropriateness of tools to measure specific learning episodes. Researchers need this information to select appropriate tools capable of supporting a practice-oriented examination of learning where task and context affect a learner's approach and performance (Laurillard, 1978; Marton & Säljö, 1976, 1984; Scouller, 1998).

The second contribution to student learning research is the development of a model that illustrates factors affecting student learning in a task- and context-specific episode of learning. This model has been the result of a combination of the literature review and the results of this thesis. It is based on Vermunt's (1998) model of assessing student learning and it incorporated themes that Curry (1983) presents in her model, such as the hierarchy of entities in student learning. Vermunt's model is insightful as it includes regulating strategies, which he describes as having the ability to control and regulate the task of learning. Regulating strategies were shown in this thesis to be used by experienced learners more frequently when studying low-imagery materials.

Vermunt's model has been extended to include factors shown in this thesis that have an impact on episodes of student learning in task and context dependent situations. This offers a more specific model that incorporates factors found in this research to affect performance. The research supports Vermunt's view that regulating strategies can compensate for other traits and factors. However, the study also showed that task, context, and prior educational attainment were also factors affecting performance.

These findings have been used to extend Vermunt's model to offer researchers a perspective on student learning. This model considers factors affecting performance in task- and context-specific examinations of episodes in learning. It is expected that this model will be useful for guiding further research into student learning. In particular it may help guide researchers on what factors to take into account when assessing innovations in task- and context-specific episodes in learning.

9.6 Limitations of this thesis

One limitation of this research was that it did not record the response times in either the study activity or the recall activity in Study 2. Comparatively, de Jong et al.

(1998) found a major effect, evident in response times, between using animations, static graphics and no graphics. Booher (1975) also found a strong effect in response times when participants completed tasks based on using high pictorial-based instruction. Recording response times in the study of instructional materials and the completion of the two introspective reports may have provided some further valuable information into learning processes. This may have been another indicator of the degree of cognitive overheads presented by particular visual representations. Ericcson & Simon (1984) have not found latency times to be particularly useful, however in this thesis they may have provided better indications of the effects using of either high-imagery or low-imagery visual representation.

The method used in Study 2 to collect student's cognitive processes could have been replaced by using concurrent think-aloud protocols. This could have provided information about the cognitive activities during task processing. The introspection reports used in this thesis were after the event and limited in their reports. Concurrent think aloud protocols, while arguably altering the nature of the task (Richardson, 1998a), might have provided more information about the kinds of meta-cognitive strategies and processes participants' employed during study and recall activities.

The visual representations used in both studies could have been better quality. Using high quality diagrams, that provided a greater distinction between the types of visual representations used in Study 2, may have indicated more significant differences. A graphic designer would have provided better representations, more capable of providing concrete meanings. This highlights some of the problems facing academics, as designing their own visual representations of information may be limited by their skill in using drawing tools rather than their imagination. The cost of employing a graphic designer was impractical in the thesis, but future research could benefit from professional visual representations being included.

The number of students sampled in Study 1 and Study 2 was small which mitigates against establishing statistical precision. The study was designed to adopt a more in-depth review of students' learning outcomes and processes that required an examination of individuals. However larger numbers in the study may have produced more convincing results.

While the participants in Study 2 were novices in concurrency they were not novice learners. This was shown to have an impact on the results, as those with better educational qualification scored better on the tests. Experienced learners have developed strategies to cope with learning that may be transferable between topic areas. A future study could select students who were both novice learners and novices in the domain to observe more marked differences in the effects of studying high versus low-imagery visual representations.

As with many studies there is always the dilemma of obtaining participants in a study. The students in both studies were paid volunteers and are arguably self-selecting. Thus, their participation could skew the results of the studies, given the addition factors of the unnaturalisitc setting of the university and external motivation through payment. However the students were selected from a pool of volunteers and were equated in Study 1 on gender and in Study 2 on prior topic knowledge. Additionally their profile was measured against the student population for the course they were studying and they were considered to be representative.

While the triangulation approach was useful for gaining information about issues from a range of perspectives, it can produce a large volume of data that can be difficult to co-ordinate. Despite this, the triangulation approach produced useful information, although in hindsight structuring the experiments more tightly would enable closer cross-links between experimental results.

Other changes to the methods adopted in the study would be the use of individual difference tests to assess learning. The field independence and learning style questionnaire were not useful. This has led me to reflect on the whole issue of categorising learners and whether it is appropriate or useful to do so. In future work I would be more likely to adopt an approach that categorises learning approaches in a similar manner to other research by Di Paolo (2001) and research conducted by Richardson (2000; submitted).

9.7 Future Work

This research has identified visual representations as being useful for students. Moreover, it forms the cornerstone for further research and valuably identifies four areas fruitful for research. These are as follows:

1. An investigation of students' interpretations of visual representations to establish what the range of interpretations might be and what factors affect interpretation.

2. An investigation into a method that distinguishes between different kinds of visual representations. This is linked to the previous research identified in point 1, where it is necessary to understand what factors affect interpretation in order to devise a method that distinguishes between them.

3. An investigation of the use of visual representations for other platforms such as the web and hand-held devices, to assess which students find useful.

4. An investigate into the use of different levels of diagrams progressing from high-imagery to low-imagery and their effectiveness for a range of learners based on their experience as learners and of the domain.

9.8 Summary

This final chapter has outlined the main achievements of this thesis. These include: the finding that visual representations have positive influences on students, the finding of prior educational attainment as a factor affecting performance, the finding of functional knowledge as a factor affecting performance, the finding that high-imagery visual representations have a positive impact on learning, the development of guidelines for information representation in instructional materials, the development of a model to illustrate factors affection task- and context-specific episodes in learning, the finding of academics' lack of reflective practices in representation design, the comparison and contrast of expert-novice differences in representation preference and perception, the identification of dual processing as a theoretical basis for understanding the variance in research results in visual representations, the confirmation of the Verbal/Imager dimension in the Cognitive Style Analysis test as an predictor of performance, the finding that the Group Embedded Figures Test was not useful in predicting preference, performance or learning process, the finding that the Learning Style Questionnaire was not useful in predicting preference, performance or learning process, a critique of the individual difference literature and a critique of the visual representation literature.

The implications for educational technology are that visual representations offer advantages for learners in understanding conceptually difficult areas. Additionally high-imagery representations can be useful for learners inexperienced in the domain. This means that information can be represented more accessible for a range of learners. This may have impact on the design of representations for other platforms such as the web, interactive digital television, and hand-held devices.

The implication for computer science is that high-imagery visual representations may more readily assist inexperienced learners understand abstract concepts in computing. Additionally they may also enable students to more readily understand the behaviour of invisible computing processes.

The implications of this thesis for research in student learning include information about the general versus the specific nature of the information offered through individual difference tests. The thesis also provides a model that illustrates the factors affecting performance in task- and context-specific episodes in learning. This is aimed at facilitating future research into practice-oriented studies of learning.

The limitations of this thesis include the quality of the visual representations, lack of time latencies recorded in Study 2, the sample size and selection in Study 2, and the retrospective reporting of the learning processes.

There are four areas that have been identified for future study. These include investigations into the interpretation of visual representations, distinction between visual representations, the use of visual representations on different platforms, and the use of different levels of imagery in visual representations with a range of learners.

I hope that this thesis has provided a thorough analysis of the issues raised which has implications for educational technology, computer science and research into student learning and which identifies fruitful areas for future research.

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Appendix A: Sample Instruction for Card Sorts

Sample Instructions

You will be given some learning materials to sort. Each learning material will have the name of a topic written on it.

We would like you to sort the learning materials into groups, using one criterion at a time. When you have finished sorting, please tell us what the criterion was for that sort, and what the groups were into which you sorted the learning materials, so that we can record this. Once this has been done, we would like you to sort the learning materials again, using a different criterion, and then to keep on sorting them until you have run out of criteria.

For example, if the task was sorting different types of car, you first criterion might be "place of manufacture" and the groups might be "American", "British", "French", etc.; the second criterion might be "cost", with the groups being "expensive", "medium" and "cheap".

You are welcome to use any criteria you like, and any groups you like, including "don't know", "not sure" and "not applicable". The main thing is to use only one criterion in each sort – please don't lump two or more in together. If you're not sure about something, just ask.

You may have noticed that the learning materials are numbered: this is for convenience when recording the results. The numbering is random, so please don't use that as a criterion for sorting!

If you have any comments or questions, then please say, and we will sort them out.

Thank you for your help.

Appendix B: Card Sort Coding Sheet

Card Sort Coding Sheet

Study Number	
Respondent Name/ID number	
Date	

Sort Number	
Criteria	
Groups	Cards

Sort Number	
Criteria	
Groups	Cards

Card Sort Coding Sheet

Study Number	**1**
Respondent Name/ID number	**1**
Date	**18th April 2000**

Sort Number	**1**
Criteria **Whether they contain tables or not**	
Groups	Cards
Tables	**13, 11, 4**
No Tables	**1, 2, 3, 5, 7, 8, 9, 10, 12, 13, 14, 15, 16**

Sort Number	**2**
Criteria **Easy to read**	
Groups	Cards
Easy	**13, 11, 4, 12**
Hard	**1, 2, 3, 5, 7, 8, 9, 10, 13, 14, 15, 16**

Appendix C: Example of Card Sort Materials

An outline of a compiler

Any program not already written in the **native code** (or **machine code**) of the processor on which it ultimately is to run must be converted to native code. There are two common approaches to this problem only one of which will concern us here. This is to translate the entire source code program into a single machine code program, and then run the machine code. A translator that adopts this approach is called a **compiler**.

The first phase is for a programmer to design a program to perform the required task, then to code program in a programming language such as C. This is typed in and saved on a file on disk.

The compiling process, then, goes something like this.

Start the *compiler and tell it where to find the program* (in other words, give it the filename). The compiler will then go through the translation process. There will be several passes involved one to transform the characters of the program to symbols that the computer can recognise. Then it analyses those symbols lexically (determine their significance) by comparing them to the pre-defined symbols allowed in the C programming language. The compiler then checks the way these symbols are organised to make sure they are syntactically correct. It finally writes a machine language version of the program to disk. However, it won't have included the machine code for any general functions your program uses.

So you must then tell a program called the **linker** the name of any general functions you are using. Code for these is stored on disk in the form of a library. The linker searches your program looking for functions that aren't defined within it. When it finds one, it looks in the library for it, and links it into the program. Finally it will have created a pure machine code program which it saves to disk.

At last you have a machine code program that can be started from disk. The process is fairly painless, if somewhat longwinded.

For example, a C program might contain a line that says

```
int a,x;
```

And another that says

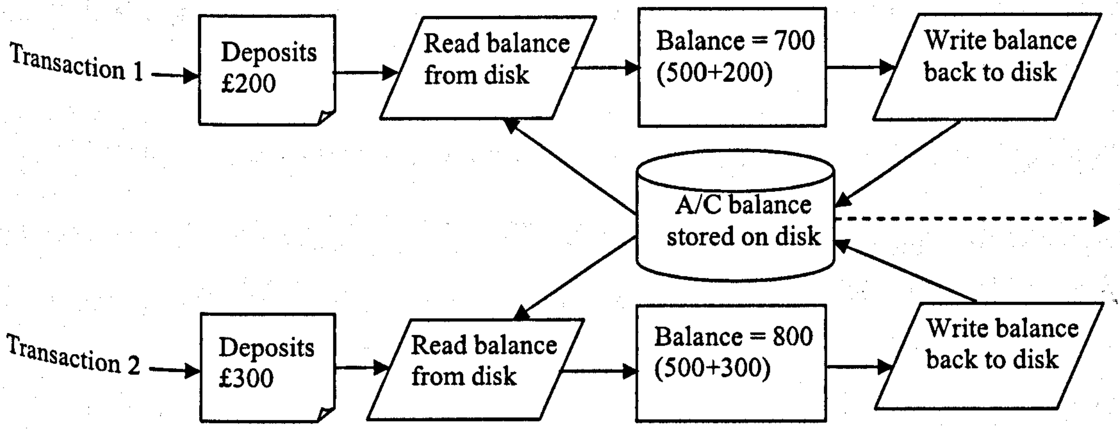
```
x=sqr(a);
```

The compiler identifies **int** as a symbol meaning what follows is defined as an integer, **a** and **x** as symbols which give a name to two integers, the equals sign as an arithmetic operator and the parenthesis as meaning that the symbols enclosed are those being operated on. (The semicolon marks the end of a programming expression and **sqr** names a general function).

2

Concurrency Control

In an ordinary file system if two users are updating a file at the same time, the READ and WRITE commands will be carried out in the order received. Consider what happens in a banking system if two transactions want to access the same account at the same time. The account initially contains 500 pounds, and the transactions are to deposit 200 and 300 pounds, respectively.

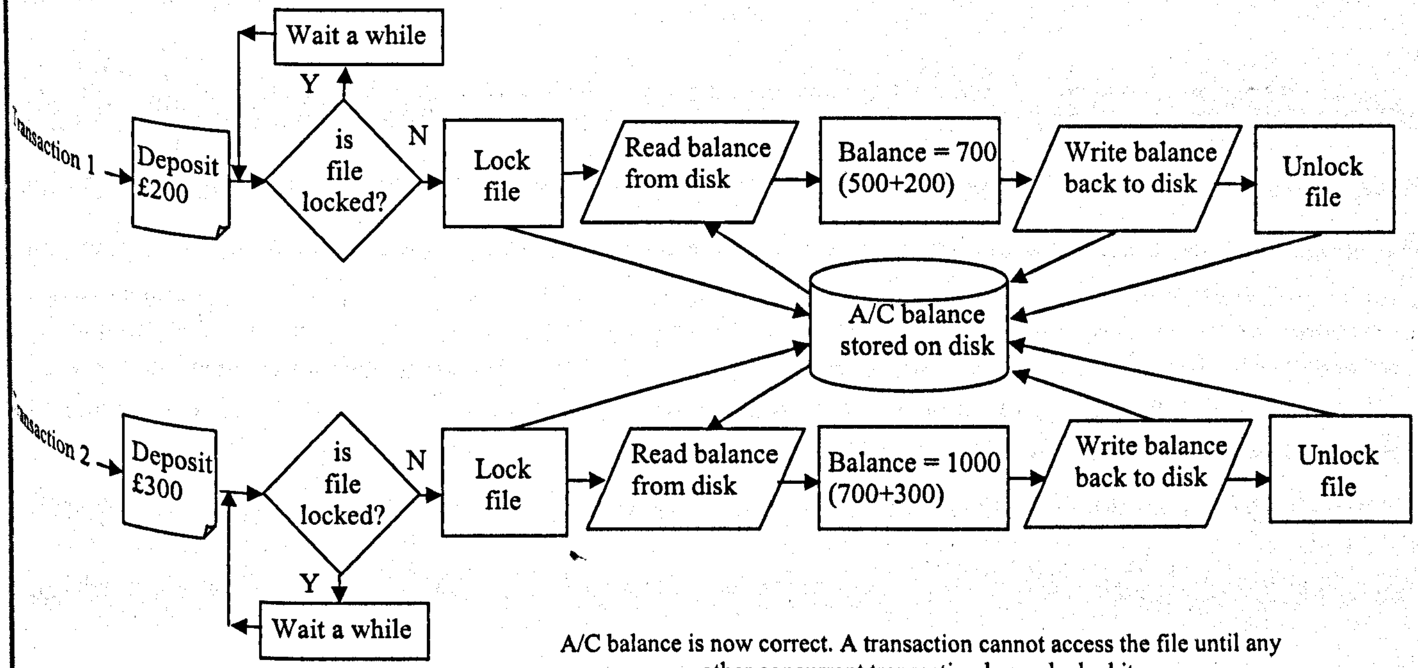


The final balance should have been 1000 but as the transactions happened simultaneously the final balance written back to the disk is 800.

If transaction 2 had been a little bit slower, the final balance written back to disk would have been 700. In either case, because the two updates are **interleaved,** the final result is wrong. What is needed is a way to ensure that first accesses the information then the other, in either order, but not interleaved as above.

How is it possible to control this type of situation?

The diagram below illustrates how **file locking** is used as a concurrency control technique



A/C balance is now correct. A transaction cannot access the file until any other concurrent transaction has unlocked it.

The property of having simultaneous updates yield a result that is equivalent to having the updates run sequentially in some order is called **serializability.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

3

An Introduction to Data Types

A *data type* is what the words say it is, namely a type or category of data. Each variable can hold only one type of data. In our sample Pascal program all variables were of type **integer.** That means that their values must be integers. An integer is any whole number such as:

38 0 1 89 3987 -12 -5

The value of a variable of type **integer** cannot be a fraction such as ½ or 3.1416. Fractions are numbers of another data type called **real,** which we will discuss later in this section.

Variables usually need to be *declared,* that is, the type of the variable must be stated. In virtually all programming languages, the rules for writing things down are very strict.

There are two reasons for requiring these declarations: to clarify your thinking by reminding you of what type of data the variable will be used for and to provide information to the compiler. Remember that the computer has only strings of zeros and ones in memory. In order to treat these strings as integers, it uses a code to encode each integer as a string of zeros and ones. In order to treat these strings as letters, it uses a different code to encode letters as strings of zeros and ones. The declaration tells the compiler and ultimately the computer what code to use.

Numbers that include a fractional part, such as the ones below, are of type **real:**

2.71828 0.098 -15.8 100053.98

Numbers are either **integer** or **real,** and must be written according to the prescribed rules for their data type. Variables defined as type **integer** must not contain a decimal point. Variables defined as type **real** may be written in two different forms. The simple form for **real** variables is like the everyday way of writing decimal fractions: it must contain a decimal point and must contain at least one digit before and one digit after the decimal point. A number may not contain a comma. Hence none of the following are allowed as type **real** (or of type **integer**):

1,000 .009 -.05 72.

It is important to remember that when you are declaring a variable that will store the result of division operation that it is declared as a real. This is because most division operations produce a fractional answer. So, if **N1/N2** means divide the value of **N1** by the value of **N2,** the variables **N1** and **N2** might be of type **integer** or of type **real,** but the variable **Z** can only be of type **real:**

Z := N1/N2

Conceptually, every whole number is both an integer and a real number. However, the computer makes a distinction between whole numbers considered to be of type **integer** and whole numbers considered to be of type **real.** In particular, the constant for the **integer** three is written **3** whereas the constant for the **real** number three is written **3. 0.**

The type for letters or, more generally, any single symbol, are frequently called *characters.* A variable of type **character** can hold any character on the input keyboard. So, for example, X could hold an **'A'** or a **'+'** or an **'a'**. If both upper- and lower-case letters are available, they are considered to be different characters. Consider this example program segment:-

```
program Tricky(input, output);
  var X, Y:          char;
begin
  X:='A';
  Y:=X;
  writeln('The first value of Y is:');
  writeln(Y);
  Y := 'X';
  writeln('The second value of Y is:');
  writeln(Y);
  writeln('I hope this helped to explain quotes.')
end.
```

Sample Dialogue

```
The first value of Y is:
A
The second value of Y is:
X
I hope this helped to explain quotes.
```

The single quotes indicate that we literally mean the letter. Hence, **X** is used for a variable named **X,** whereas **'X'** is used for the upper case version of the third from the last letter of the alphabet. This is an important distinction to remember when using characters.

4

An Introduction to Data Types

A *data type* is what the words say it is, namely a type or category of data. Each variable can hold only one type of data. Variables usually need to be *declared,* that is, the type of the variable must be stated. In virtually all programming languages, the rules for writing things down are very strict. There are two reasons for requiring these declarations: to clarify your thinking by reminding you of what type of data the variable will be used for and to provide information to the compiler. Remember that the computer has only strings of zeros and ones in memory. In order to treat these strings in a particular way (say to add), it uses a specific pattern of zeros and ones. In order to treat these strings in a different way, it uses a different pattern of zeros and ones. The declaration tells the compiler and ultimately the computer what pattern to use.

There are 3 different data types that we are going to consider, **integer, real** and **character.**

1. **Integer**
   The type **integer** means that its value must be a whole number. It cannot contain commas, decimal points, characters or symbols

   Examples **38** **89** **-12** **29**

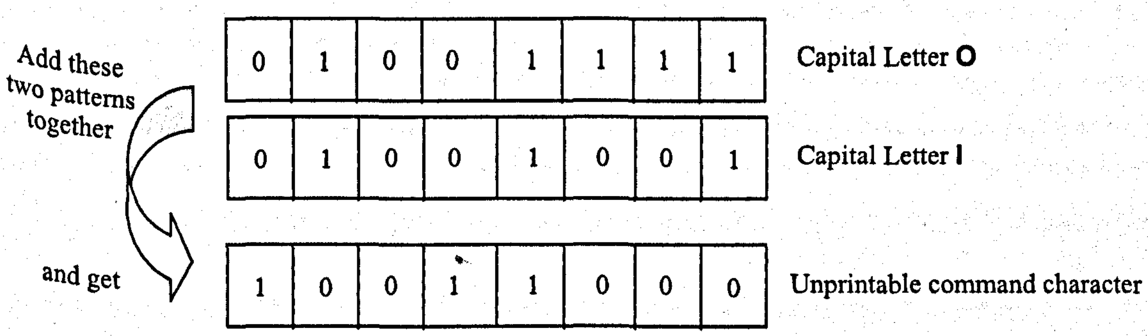
2 **Real**
   The type **real** means that its value must be a decimal fraction. Variables defined as type **real** contain a decimal point and at least one digit before and after the decimal point. A **real** may not contain a comma, a character or a symbol.

   Examples **2.71828** **0.098** **-15.8** **4.9**

3 **Character**
   This type stores letters or, any single symbol, and are more frequently called *characters.* A variable of type **character** can hold any character on the input keyboard. Note that if both upper- and lower-case letters are available, they are considered to be different characters. It will also stored numbers but not in the same way that a real or integer type will. That means that if it is recorded as a character you can not perform any mathematical operations on the data.

   Examples **A** **b** **@** **9** **%** **£** **(** **+** **#** **x** **X** **$**

Consider what happens in the situation where we want to add together **I and O.** While **I** and **O** look like the numbers 0 and 1 they are in fact capital letters.



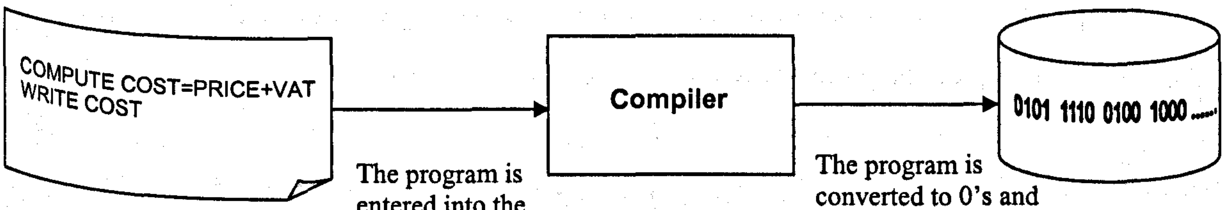
0	1	0	0	1	1	1	1	Capital Letter **O**
0	1	0	0	1	0	0	1	Capital Letter **I**
1	0	0	1	1	0	0	0	Unprintable command character

If we do not have a mechanism in the computer for deciding how to treat these information items the computer could record their patterns as characters but allow mathematical computations to be performed on them. Then, as in this case, the result would be meaningless. This is why declaring variables as types which define their usage actually helps protect the data from becoming meaningless due to an inappropriate arithmetic operation.

5

An outline of a compiler

Any program written in a high-level programming language (one intended to help the programmer solve a problem in a particular domain, like business) must be converted to a native code for the machine — essentially a series of codes consisting of 0's and 1's. A translator that does this job is called a compiler.



The program is entered into the compiler for translation

The program is converted to 0's and 1's so the computer can understand the commands

This means that the compiler reads the high-level language program and

- identifies the individual keywords that the language uses to specify types of data and actions
- checks that statements consisting of keywords, labels for data and data types are correctly written and consistent
- writes the resulting native code program to a file on disk — the native code program is what the computer is capable of running

Example
The statement in COBOL

```
COMPUTE COST = PRICE + VAT.
```

contains the keyword COMPUTE plus key symbols for equals (=) and add (+). It also contains three labels for data: COST, PRICE and VAT. Earlier in a COBOL program these would be defined as, for example,

```
03   COST     PICTURE ZZZ9.99.
03   PRICE    PICTURE ZZZ9.99.
07   VAT      PICTURE .999 VALUE.175.
```

VAT is a constant (always the same value), while the keyword PICTURE means "treat this data as [type]" and the Z's and 9's refer to numeric data.

Concurrency Control

In an ordinary file system if two users are updating a file at the same time, the READ and WRITE commands will be carried out in the order received. Consider what happens in a banking system if two customers each deposit money to the same account at the same time. The account initially contains 500 dollars, and the customers want to deposit 200 and 300 dollars, respectively. The following sequence of actions might occur.

1. Customer 1's program accesses the current balance and sees that it is 500.
2. Customer 2's program accesses the current balance and also sees that it is 500.
3. Customer 1's program updates the new balance to be current balance + 200 = 700.
4. Customer 2's program updates the new balance to be current balance + 300 = 800.

The final result is a new balance of 800. If customer 1 had been a little bit faster, the final new balance would have been 700. In either case, because the two updates are **interleaved,** the final result is wrong. What is needed is a way to ensure that first customer runs his program and then the other, in either order, but not interleaved as above.

Question
How is it possible to control this type of situation?

Answer
One way is for whichever program accesses the current balance first to exclude any other program from accessing it until the update is complete.

For Example:

1. Customer 1's program accesses the current balance and sees that it is 500 and locks the file so no other program can access it.
2. Customer 2's program accesses the current balance but as the file it locks the access is disallowed and keeps retrying.
3. Customer 1's program updates the new balance to be current balance + 200 = 700 and writes this back to the file. The file is now unlocked.
4. Customer 2's program is now allowed to access the current balance. It locks the file so no other program can access it. It updates the new balance to be current balance + 300 = 1000 and writes this back to the file. the file is now unlocked.

Many file servers offer this form of file **locking** to their clients as a concurrency control technique. When a file is locked by one client, all attempts to use or lock the file by other clients are made pending by the server.

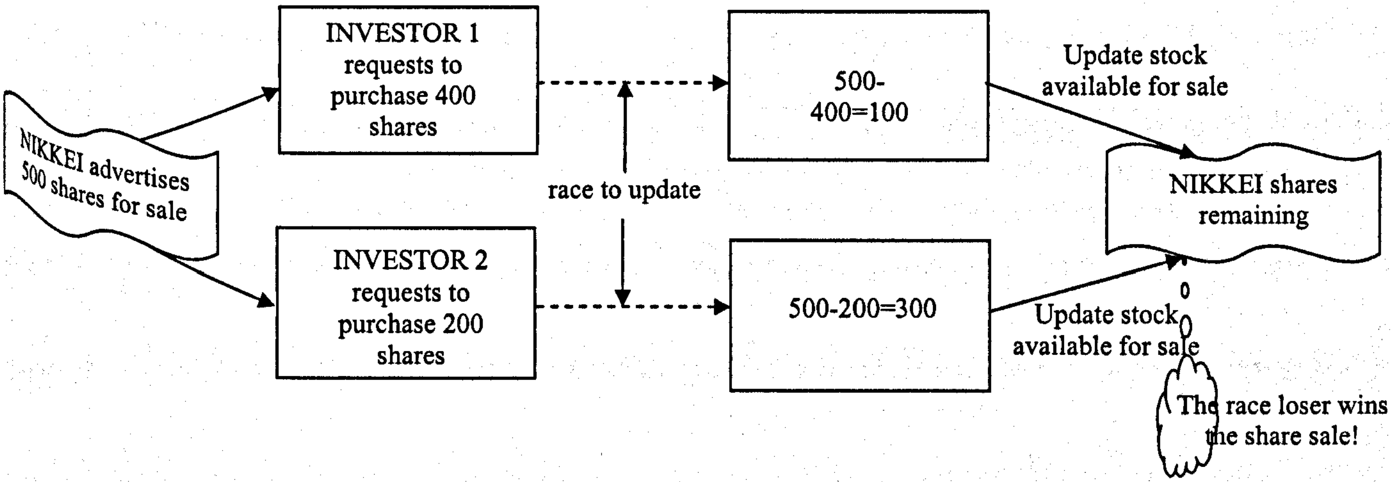
The property of having simultaneous updates yield a result that is equivalent to having the updates run sequentially in some order is called **serializability.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

Concurrency Control

In an ordinary system if two users are updating records at the same time, the READ and WRITE commands will be carried out in the order received. Let us consider this in context.

The NIKKEI stock exchange allows electronic purchases of shares from its stock exchange on a worldwide basis. This means that any authorised investor can purchase stock electronically via a computer link. Consider what happens if two investors each want to buy the same shares at the same time. The total shares available for purchase are 500 and the investors want to purchase 400 and 200 shares, respectively. There is an obvious problem with this as there are not enough shares for both investors. The obvious solution would be to allocate the shares to the first investor to complete the electronic purchase. However consider the situation if the following events occurred.

- INVESTOR 1 places a request-to-purchase order of 400 shares
- INVESTOR 2 places a request-to-purchase order of 200 shares



- INVESTOR 1's requests to purchase 400 shares at the same time INVESTOR 2 requests to purchase the same shares.
- There is now a race between INVESTOR 1 and INVESTOR 2 to see who can complete the electronic purchase first and thus gain the shares.

However, because they both understand the shares available to be 500, each investors purchase proceeds. Instead of the first investor to complete the deal being recorded as the purchaser, it is the last deal that actually is attributed as buying the stock. In this case the same shares have been sold twice and an incorrect number remains on sale.

The problem occurred because the two updates are **interleaved,** i.e. instead of each deal happening serially (one after the other) parts of one deal happen almost simultaneously with parts of another deal, and therefore neither can be guaranteed to be completely correct. What is needed is a way to ensure that one investor's request to purchase is completed and then the other, in either order, but not interleaved as above.

Many file servers offer this form of file **locking** to their clients as a concurrency control technique. When one investor locks the records, all attempts to use or lock the records by other investors are held in line by the server.

The property of having simultaneous updates yield a result that is equivalent to having the updates run sequentially in some order is called **serializability.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

8

An Introduction to Data Types

Variables usually need to be *declared,* that is, the type of the variable must be stated. In virtually all programming languages, the rules for writing things down are very strict. There are two reasons for requiring these declarations, first to clarify your thinking by reminding you of what type of data the variable will be used for and second to provide information to the compiler.

A *data type* is what the words say it is, namely a type or category of data. Each variable can hold only one type of data. There are 3 different data types that we are going to consider, **integer, real** and **character.**

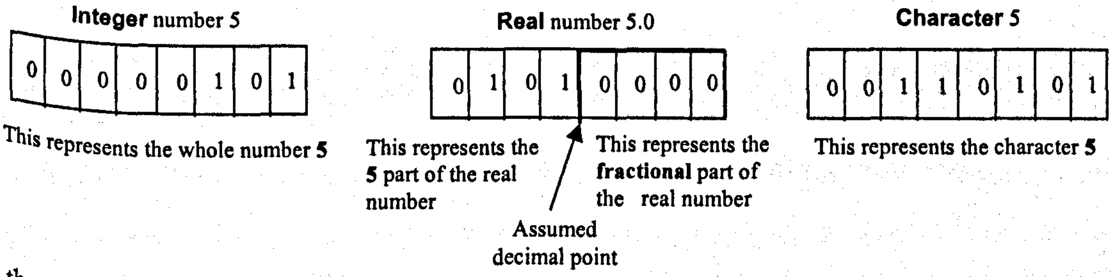
The type **integer** means that its value must be a whole number. It cannot contain commas, decimal points, characters or symbols. Some examples of integer numbers are **38 0 1 89 3987 -12 -5 2**

The type **real** means that its value must be a decimal fraction. Variables defined as type **real** contain a decimal point and at least one digit before and after the decimal point. A **real** may not contain a comma, a character or a symbol. Some examples of real numbers are **2.71828 0.098 -15.8 100053.98 4.9**

The **character** type stores letters or, any single symbol, and are more frequently called *characters.* A variable of type **character** can hold any character on the input keyboard. Note that if both upper- and lower-case letters are available, they are considered to be different characters. It will also stored numbers but not in the same way that a real or integer type will. That means that if it is recorded as a character you can not perform any mathematical operations on the data. Some examples are **A b @ 9 Z % £ (+ # G x X $**

Remember that the computer has only strings of zeros and ones in memory. In order to treat these strings as meaningful pieces of information, it encodes them according to the type of information it is storing.

Consider how it will store the integer number 5, the real number 5.0, and the character 5.



In the world outside the computer these numbers have the same value, but inside the computer they are encoded differently. This means that it will store characters differently from numbers, and even different types of numbers will be encoded differently. This is why declaring variable types is important: it tells the compiler and ultimately the computer what code to use.

Consider the following list, which of these numbers can be stored as **integers, reals** and **characters**?

45 10.1416 72 99 ½ 987 20. 81.29. 19 9.828 –13 0.0001 -15.8 –6 1,000 4.9 IO

The **integers** are

45 72 99 987 19 -13 -6 (**IO** is not the number ten but the letters **I** and **O**)

The **reals** are

10.1416 81. 29 9.828 0.0001 -15.8 4.9

The **characters** are everything in the list. Even the ½ symbol will have an internal representation in the computer that will allow this symbol to be reproduced. Conceptually, every whole number is both an integer and a real number. However, the computer makes a distinction between these two. In some languages an integer will be converted to a real automatically by putting in a decimal point.

9

An outline of a compiler

Any program not already written in the **machine language** of the processor on which it ultimately is to run must be converted to **native code**. One approach to conversion is to compile a program using another program called a compiler. A compiler is based on two assumptions:

(i) That the source program is a sequence of characters stored in a file on disk;

(ii) That the target program will also be a sequence of characters stored in a file on disk.

These assumptions mean that the compiler will have to read the sequence of source program characters, translate the characters into the target program by some means, and store the target (machine language) program back into a file. As it is easier for the compiler to deal with symbols rather than individual characters, the compiler will therefore have to convert the source program characters into symbols, before attempting the translation into the target program.

Part of the compiler, similar to a spelling checker, is responsible for examining the stream of source program characters and identifying individual symbols. It needs to check the source program against a predefined list (the language), rather like we unconsciously do when we communicate in our own language. Below is a list of symbols the Pascal programming language recognises.

Key	Signifies	Key	Signifies	Key	Signifies	Key	Signifies
Keywords				**Operators**			
const	constant	if	These two statements are used in conjunction: **if** statement A is true **then** carry statement B	=	equals	>	Greater then
var	variable	then		-	minus	<	Less than
type	define the data type	else	When an **if** statement is false the statements following the **else** are carried out	+	plus		Not equal to
record	record	repeat	Used in conjunction: a set of statements are repeated until a condition is true	*	times	> =	Greater than or equal to
procedure	a group of statements to be treated as one unit	until		/	divide	< =	Less than or equal to
array	Holds a collection of related data items	do	carry out the following statements	**Punctuation**		**Constants**	
program	Identifies the beginning of the program	while	while a given statement is true carry out the follow statements	,	Separated items in a list	integer	Whole number
function		**Identifier**		.	Decimal point	char	Alphabetic or numeric
	Function: it carries out a set of statements and returns a value	Any sequence of letters and digits other than the keywords beginning with a letter can be an identifier that can be used to name an item of data or a procedure		;	Semicolon and end of statement marker	string	A collection of characters
				:	Colon and type delimiter	real	Decimal number

The example below shows how a compiler examines code to find and define symbols. (You can try this yourself before looking at the solution.)

Example

Draw up a table of symbols that hold the user-defined identifiers in the following program segment:

```
const
    a=2;
    b=1.0;
    star='*';
var
    total:integer;
    sum:real;
```

Solution

identifier	type	class	internal computer representation
a	integer	constant	2
b	real	constant	1.0
star	char	constant	42
total	integer	constant	Only know when the program runs
sum	real	constant	Only know when the program runs

The output from this part of the compiler is then checked to make sure statements are formed correctly — a kind of grammar check!

10

An Introduction to Data Types

Variables usually need to be *declared,* that is, the type of the variable must be stated. In virtually all programming languages, the rules for writing things down are very strict.

There are two reasons for requiring these declarations:

1. To clarify your thinking by reminding you of what type of data the variable will be used for
2. To provide information to the compiler.

Remember that the computer has only strings of zeros and ones in memory. In order to treat these strings as meaningful pieces of information, it encodes them according to the type of information it is storing. This means that it will store characters differently from numbers, and even different types of numbers will be encoded differently. This is why declaring variable types is important: it tells the compiler and ultimately the computer what code to use.

A *data type* is what the words say it is, namely a type or category of data. Each variable can hold only one type of data. There are 3 different data types that we are going to consider, **integer, real** and **character.**

Data Type	Description	Example
Integer	The type **integer** means that its value must be a whole number. It cannot contain commas, decimal points, characters or symbols	**38 89 -12 29**
real	The type **real** means that its value must be a decimal fraction. Variables defined as type **real** contain a decimal point and at least one digit before and after the decimal point. A **real** may not contain a comma, a character or a symbol.	**2.71828 0.098** **-15.8 4.9**
character	This type stores letters or, any single symbol, and are more frequently called *characters.* A variable of type **character** can hold any character on the input keyboard. Note that if both upper- and lower-case letters are available, they are considered to be different characters. It will also stored numbers but not in the same way that a real or integer type will. That means that if it is recorded as a character you can not perform any mathematical operations on the data.	**A b @ 9** **% £ (+** **# x X $**

Example

Consider the following list, which of these numbers can be stored as **Integer, real** and **character?**

45 10.1416 72 99 ½ 987 20. 81.29.19 9.828 –13 0.0001 -15.8 –6 1,000 4.9 IO

Answer

The **Integers** are

45 72 99 987 19 -13 -6 (**IO** is not the number ten but is capital **I** and capital **O**)

The **reals** are

10.1416 81. 29 9.828 0.0001 -15.8 4.9

Conceptually, every whole number is both an integer and a real number. However, the computer makes a distinction between these two. In some languages an integer will be converted to a real automatically by putting in a decimal point.

The **characters** are everything in the list. Even the ½ symbol will have an internal representation in the computer that will allow this symbol to be reproduced.

11

Entity-Relationship Modelling

Entity-relationship modelling is used in system design as a means of **rationalising** the information. In other words to try and make database maintenance as efficient as possible. Consider the situation when all the information is stored in a large file. For example, if a university was to store all student and course information in one file. It would contain multiple records for students who were enrolled in more than one course.

ID	Name	Address	Course Code	Course Description	Price
OU45	Josephine Bloggs	12, Main Road, Milton Keynes	M206	Computing for Beginners	100.00
OU45	Josephine Bloggs	12, Main Road, Milton Keynes	M373	Advanced Mathematics	85.00
OU45	Josephine Bloggs	12, Main Road, Milton Keynes	T102	Technology and Society	90.00

The problem with this file is that if Josephine changes her address then 3 records have to be changed. However, if we rationalised this into two files that are related, then maintaining the integrity of the information will be easier (information is only useful when it is up-to-date). It is this rationalisation in database design that entity-relationship modelling is trying to support.

Entity-Relationship modelling has two basic components: **entities** and **relationships.**

Entities

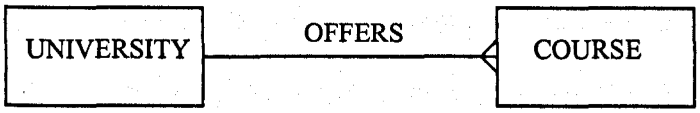
An entity can be described as object about which descriptive information is to be stored, which is capable of independent existence, and which can be uniquely identified. The entity may be an *object* such as as a car; or an *event* such as a football match. The descriptive information of the entity is known as its attributes. For example, if we were to model our file of student information as described above we would have the following entities and attributes.

The attributes for this entity are ID, Name, Address

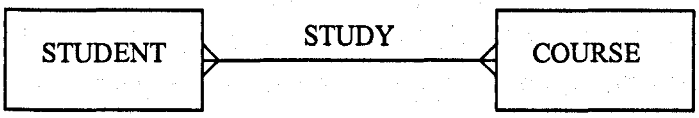
The attributes for this entity are Course Code, Course Description, Course Fee

Relationships

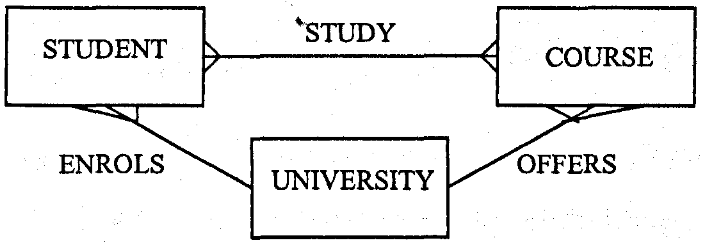
A relationship shows how the entities are related. They may be one-to-one, one-to-many or many-to-many. For example, the relationship between the entity types UNIVERSITY and COURSE is OFFERS, i.e. a university offers many courses. The *many* part of the relationship is represented graphical using what is know as a *crow's foot.*



The relationship between the entity types STUDENT and COURSE would be many-to-many as a course may have several students and a student can study several courses.



These entities can be put together and can show a third relationship can you identify it?



A university enrols many students but a student can only enrol in one university

12

Entity-Relationship Modelling

The reason for using entity-relationship modelling in the design of a system is to try and rationalise the information, in other words to try and make the maintenance of the database as easy as possible. Consider the situation when all the information is stored in a large file. For example, let us consider a video store that keeps a record of its video loans.

Member No	Name	Address	Video No	Video Description	Copy No	Hire Fee
71	Joe Bloggs	12, Main Street, London	2795	Titanic	5	2.00
90	Mary Sudds	22, Palace Street, London	2795	Titanic	3	2.00
90	Mary Sudds	22, Palace Street, London	1234	Men in Black	12	2.50
71	Joe Bloggs	12, Main Street, London	4242	Tomorrow Never Dies	15	3.00

The problem with this file is that if Joe changes address then 2 records have to be changed.. However, if we rationalised this into two files that are related, then maintaining the integrity of the information will be easier (information is only useful when it is up-to-date). It is this rationalisation in database design that entity-relationship modelling is trying to support. The two basic components of Entity-Relationship modelling are **entities** and **relationships.**

Entities

An entity can be described as object :-

(i) about which descriptive information is to be stored
(ii) which is capable of independent existence
(iii) which can be uniquely identified.

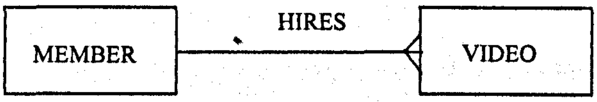
The entity may be an *object* such as a car; or an *event* such as a football match. The descriptive information of the entity is known as its attributes. For example, if we were to model our file of video loan information as described above we would have the following entities and attributes.

The attributes for this entity are Member No, Name, Address

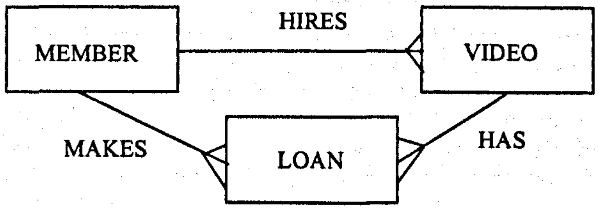
The attributes for this entity are Video No, Video Description, Copy No, Hire Fee

Relationships

A relationship shows how the entities are related. They may be one-to-one, one-to-many or many-to-many. For example, the relationship between the entity types MEMBER and VIDEO is HIRES, i.e. a MEMBER can hire many videos, but only one copy of a video can be hired by a member. The *many* part of the relationship is represented graphical using what is known as a *crow's foot.*



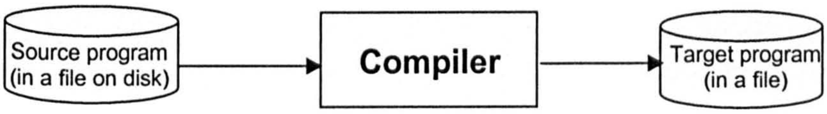
We could also include another entity called LOAN which keeps a record of who has hired what video and when it is due back.



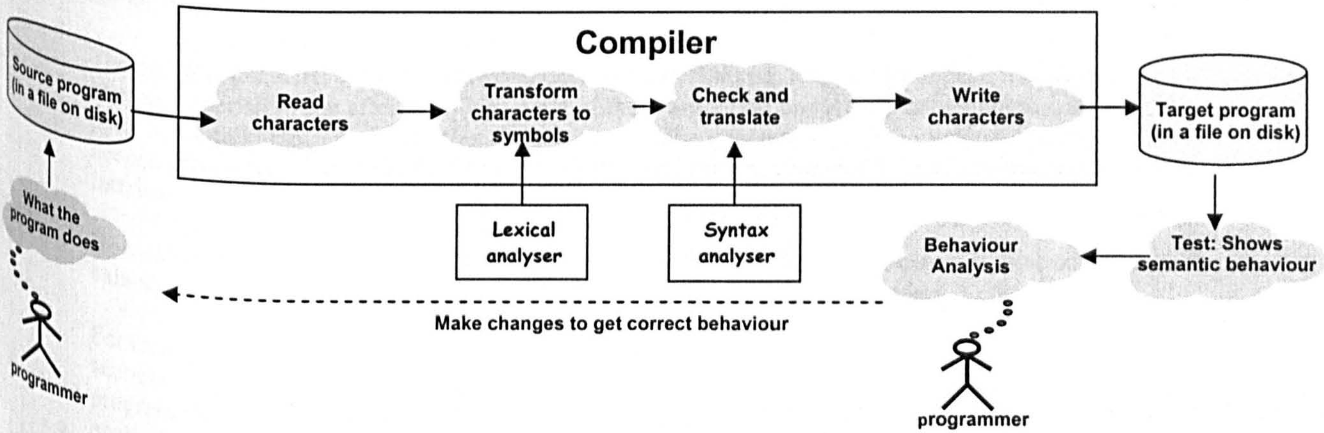
13

An outline of a compiler

Any program not already written in the **machine language** of the processor on which it ultimately is to run must be converted to **native code**. One approach to conversion is to compile a program using another program called a **compiler**. Our compiler is based the assumption that both the original and native versions of the program are sequences of characters stored on a file on disk.



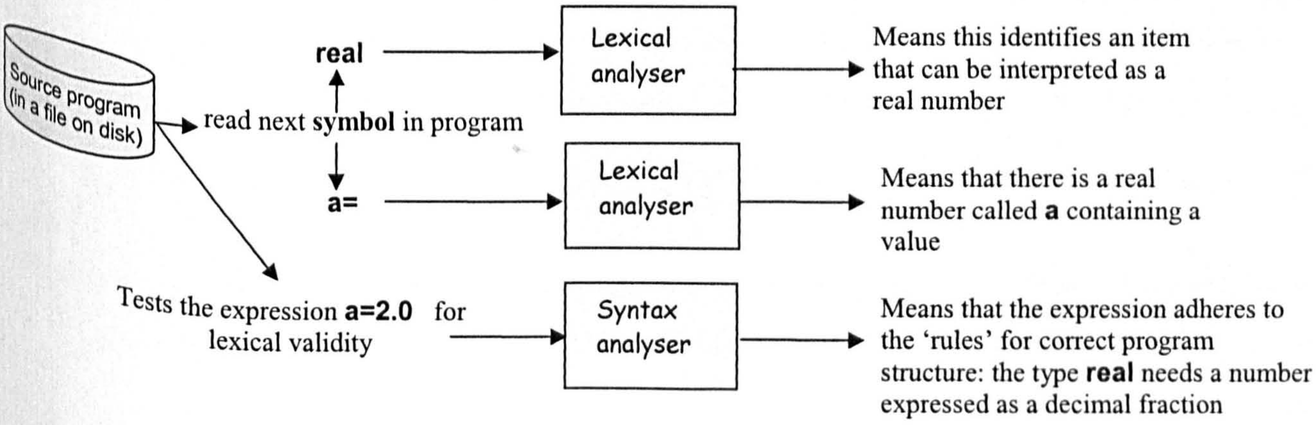
These assumptions mean that the compiler will have to read the sequence of source program characters, translate the characters into the target program by some means, and store the target (machine language) program back into a file. As it is easier for the compiler to deal with symbols rather than individual characters, the compiler will therefore have to convert the source program characters into symbols, before attempting the translation into the target program. Here is an outline of this process:



The lexical analyser is responsible for examining the stream of source program characters and identifying individual symbols. But it needs to check the source program against a predefined list (the Fortran language), rather like we unconsciously do when we communicate in our own language. Let us image that we are going to compile a Fortran program. We need to use a set of keywords that the compiler will understand as having special meaning such as the word **real** to signify a real number. Consider the following Fortran program segment:-

```
real a,b,c
a=2.0
```

The diagram below shows how keywords are interpreted as symbols and then checked for correct syntax.



Concurrency Control

In an ordinary file system if two users are updating a file at the same time, the READ and WRITE commands will be carried out in the order received. Let us consider this in context.

A Swiss bank allows more than one person to deposit into a personal account from outside Switzerland. This means that any authorised client can deposit to an account remotely using the Internet. Consider what happens if two Internet clients each deposit money to the same account at the same time. The account initially contains 500 francs, and the Internet clients want to deposit 200 and 300 francs, respectively. The events might occur in the following order.

Internet client 1's program is admitted to the information. It reads the balance of the account as 500 francs. Internet client 2's program is also admitted to the information and also sees the balance as 500 francs. Each client transfers the money and Internet client 1 updates the balance to be 700 francs. Meanwhile Internet client 2, just marginally slower, updates the balance to be 800 francs. Had Internet client 2 been a little faster, the final balance of the account would have been 700 francs. In any event, the result is incorrect as the final balance of the account should be 1000 francs.

The problem occurred because the two updates are **interleaved**, i.e. instead of each transaction happening serially (one after the other) parts of one transaction happen almost simultaneously with parts of another transaction, and therefore neither can be guaranteed to be completely correct. What is needed is a way to ensure that one Internet client is admitted and then the other, in either order, but not interleaved as above.

How is it possible to control this type of situation? One way is for whomever is first admitted to the balance information to exclude anyone else from accessing it until their update is complete.

For example, Internet client 1's program is admitted to the information. It reads the balance of the account as 500 francs and then **locks the information** so no one else can use it. Internet client 2's program tries to gain admission to the information but is excluded until the information is available again. Internet client 1 transfers the money and updates the balance to be 700 francs. When Internet client 1 has finished using the information it is unlocked so someone else can use it. Internet client 2 can now gain admission to the information and locks it so no one else can gain admission. The balance is read as 700 francs and the 300 francs deposit is added on to make the balance 1000 francs. When this action is completed the information is unlocked so someone else can use it.

Many file servers offer this form of file **locking** to their clients as a concurrency control technique. When one client locks a file, all attempts to use or lock the file by other clients are held in a queue by the server.

The property of having simultaneous updates yield a result that is equivalent to having the updates run sequentially in some order is called **serializability.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

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Entity-Relationship Modelling

The reason for using entity-relationship modelling in the design of a system is to try and rationalise the information, in other words to try and make the maintenance of the database as easy as possible. Consider the situation when all the information is stored in a large file. For example, if a supplier were to store all customer order information in one file it would contain multiple records for customers who had placed several orders.

Customer No	Name	Address	Order No	Part No	Part description	Price	Quantity	Total Price
1275	Mactronics	Lisloe Industrial Estate, Birmingham	4723	PT45	6" inch steel screws	0.05	100	5.00
1275	Mactronics	Lisloe Industrial Estate, Birmingham	4723	PT77	2" winged nuts	0.10	100	10.00
1275	Mactronics	Lisloe Industrial Estate, Birmingham	4800	PT01	Rock Hammer	150.00	1	150.00
1170	Stellites	Mill Lane Industrial Estate, Sheffield	4901	PT45	6" inch steel screws	0.05	200	10.00

The problem with this file is that if the price of part PT45 changes then 2 records have to be changed, even though there is only one piece of information that has changed. However, if we rationalised this into two files that are related, then maintaining the integrity of the information will be easier (information is only useful when it is up-to-date). It is this rationalisation in database design that entity-relationship modelling is trying to support.

Entity-Relationship modelling has two basic components: **entities and relationships.**

Entities

An entity can be described as object :-

(iv) about which descriptive information is to be stored

(v) which is capable of independent existence

(vi) which can be uniquely identified.

The entity may be an *object* such as a car; or an *event* such as a football match. The descriptive information of the entity is known as its attributes. For example, if we were to model our file of customer orders as described above we would have the following entities and attributes.

Entity name	Attributes (i.e. the type of information recorded)
CUSTOMER	Customer Number, Name, Address
ORDER	Order number, part number, part description, price, quantity, total price

Relationships

A relationship shows how the entities are related. They may be one-to-one (1:1), one-to-many (1:N) or many-to-many (N:M). For example, the relationship between the entity types CUSTOMER and ORDER is PLACES, i.e. a customer places many orders. So the relationship between CUSTOMER and ORDER is one-to-many (1:n).

CUSTOMER------------ 1:N ------------- ORDER

However the relationship REQUIRES between the entity types ORDER and PARTS would be N:M as an order has many parts and a part is required for many orders.

ORDER----------N:M-------------PART

Entity-Relationship Modelling

The reason for using entity-relationship modelling in the design of a system is to try and rationalise the information, in other words to try and make the maintenance of the database as easy as possible. Consider the situation when all the information is stored in a large file. For example, if a hospital were to store all patient and operation information in one file it would contain multiple records.

Let us consider a file that contains the following fields
Hospital Number, Name, Address, Operation Number, Operation Description, Operation Date, Surgeon

And the following records
HP25, Mary Smith, 20 Short Street, Glasgow, 19223, Appendectomy, 23/07/99, Mr Brown
HP25, Mary Smith, 20 Short Street, Glasgow, 18373, Caesarean Section, 19/05/92, Mr Sprog
HP99, Joe Dougal, 19 Long Street, Glasgow, 19001, Triple Bypass, 01/04/98, Mr Miller
HP45, Caleb Ball, 101, Mill Lane, Glasgow, 17923, Triple Bypass, 07/07/89, Mr Miller

The problem with this file is that if Mary changes address then 2 records have to be changed, even though there is only one piece of her information that has changed. However, if we rationalised this into two files that are related, then maintaining the integrity of the information will be easier (information is only useful when it is up-to-date). It is this rationalisation in database design that entity-relationship modelling is trying to support.

Entity-Relationship modelling has two basic components these are **entities** and **relationships**. An entity can be described as object about which descriptive information is to be stored and which is capable of independent existence. It can also be uniquely identified.

The entity may be an *object* such as a car; or an *event* such as a football match. The descriptive information of the entity is known as its attributes. For example, if we were to model our file of hospital information as described above we would have

Entity PATIENT, has the attributes Hospital Number, Name, Address,
Entity OPERATION, has the attributes Operation Number, Operation Description, Operation Date, Surgeon

A relationship differs from an entity in that it shows how the entities are related. The relationships may be one-to-one (1:1), one-to-many (1:N) or many-to-many (N:M). For example, the relationship between the entity types PATIENT and OPERATION is UNDERGOES, i.e. a patient undergoes one operation (i.e. at an instance in time) and this operation can only be performed on one patient. So the relationship between PATIENT and OPERATION is one-to-one (1:N).

PATIENT 1:1 OPERATION

However the relationship IS ASSIGNED TO between the entity types SURGEON and PATIENT would be 1:N as a patient is assigned to one surgeon but a surgeon has many patients assigned to him.

SURGEON 1:N PATIENT

There is also a third relationship between the entities SURGEON and OPERATION. Can you identify it?

SURGEON 1:N OPERATION

The relationship is PERFORMS: a surgeon performs many operations, but a surgeon performs only one operation.

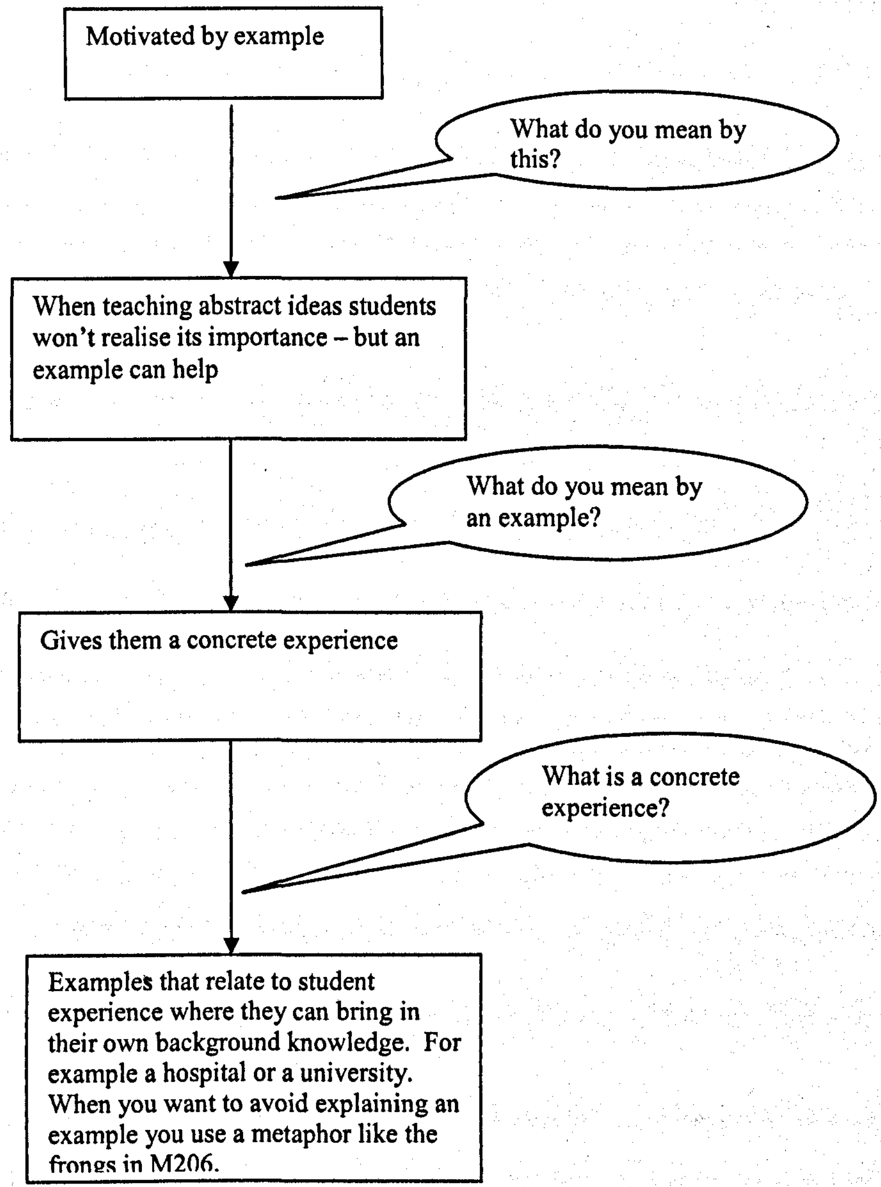
Appendix D: Laddering Coding Sheet

Laddering Coding Sheet

Study Number	
Respondent Name/ID number	
Date	

Laddering Coding Sheet

Study Number	
Respondent Name/ID number	
Date	



Appendix E: Honey and Mumford Learning Style Questionnaire

LEARNING STYLES QUESTIONNAIRE

revised 1986

This questionnaire is designed to find out your preferred learning style(s). Over the years you have probably developed learning 'habits' that help you benefit more from some experiences than from others. Since you are probably unaware of this, this questionnaire will help you pinpoint your learning preferences so that you are in a better position to select learning experiences that suit your style.

There is no time limit to this questionnaire. It will probably take you 10-15 minutes. The accuracy of the results depends on how honest you can be. There are no right or wrong answers. If you agree more than you disagree with a statement put a tick by it (✓). If you disagree more than you agree put a cross by it (x). Be sure to mark each item with either a tick or cross.

☐ 1. I have strong beliefs about what is right and wrong, good and bad.

☐ 2. I often act without considering the possible consequences.

☐ 3. I tend to solve problems using a step-by-step approach.

☐ 4. I believe that formal procedures and policies restrict people.

☐ 5. I have a reputation for saying what I think, simply and directly.

☐ 6. I often find that actions based on feelings are as sound as those based on careful thought and analysis.

☐ 7. I like the sort of work where I have time for thorough preparation and implementation.

☐ 8. I regularly question people about their basic assumptions.

☐ 9. What matters most is whether something works in practice.

☐ 10. I actively seek out new experiences.

☐ 11. When I hear about a new idea or approach I immediately start working out how to apply it in practice.

☐ 12. I am keen on self discipline such as watching my diet, taking regular exercise, sticking to a fixed routine, etc.

☐ 13. I take pride in doing a thorough job.

☐ 14. I get on best with logical, analytical people and less well with spontaneous, 'irrational' people.

☐ 15. I take care over the interpretation of data available to me and avoid jumping to conclusions.

☐ 16. I like to reach a decision carefully after weighing up many alternatives.

☐ 17. I'm attracted more to novel, unusual ideas than to practical ones.

☐ 18. I don't like disorganised things and prefer to fit things into a coherent pattern.

☐ 19. I accept and stick to laid down procedures and policies so long as I regard them as an efficient way of getting the job done.

☐ 20. I like to relate my actions to a general principle.

☐ 21. In discussions I like to get straight to the point.

☐ 22. I tend to have distant, rather formal relationships with people at work.

☐ 23. I thrive on the challenge of tackling something new and different.

☐ 24. I enjoy fun-loving, spontaneous people.

☐ 25. I pay meticulous attention to detail before coming to a conclusion.

☐ 26. I find it difficult to produce ideas on impulse.

☐ 27. I believe in coming to the point immediately.

☐ 28. I am careful not to jump to conclusions too quickly.

☐ 29. I prefer to have as many sources of information as possible - the more data to think over the better.

☐ 30. Flippant people who don't take things seriously enough usually irritate me.

☐ 31. I listen to other people's points of view before putting my own forward.

☐ 32. I tend to be open about how I'm feeling.

☐ 33. In discussions I enjoy watching the manoeuvrings of the other participants.

☐ 34. I prefer to respond to events on a spontaneous, flexible basis rather than plan things out in advance.

☐ 35. I tend to be attracted to techniques such as network analysis, flow charts, branching programmes, contingency planning, etc.

☐ 36. It worries me if I have to rush out a piece of work to meet a tight deadline.

☐ 37. I tend to judge people's ideas on their practical merits.

☐ 38. Quiet, thoughtful people tend to make me feel uneasy.

☐ 39. I often get irritated by people who want to rush things.

☐ 40. It is more important to enjoy the present moment than to think about the past or future.

☐ 41. I think that decisions based on a thorough analysis of all the information are sounder than those based on intuition.

☐ 42. I tend to be a perfectionist.

☐ 43. In discussions I usually produce lots of spontaneous ideas.

☐ 44. In meetings I put forward practical, realistic ideas.

☐ 45. More often than not, rules are there to be broken.

☐ 46. I prefer to stand back from a situation and consider all the perspectives.

☐ 47. I can often see inconsistencies and weaknesses in other people's arguments.

☐ 48. On balance I talk more than I listen.

☐ 49. I can often see better, more practical ways to get things done.

☐ 50. I think written reports should be short and to the point.

☐ 51. I believe that rational, logical thinking should win the day.

☐ 52. I tend to discuss specific things with people rather than engaging in social discussion.

☐ 53. I like people who approach things realistically rather than theoretically.

☐ 54. In discussions I get impatient with irrelevancies and digressions.

☐ 55. If I have a report to write I tend to produce lots of drafts before settling on the final version.

☐ 56. I am keen to try things out to see if they work in practice.

☐ 57. I am keen to reach answers via a logical approach.

☐ 58. I enjoy being the one that talks a lot.

☐ 59. In discussions I often find I am the realist, keeping people to the point and avoiding wild speculations.

☐ 60. I like to ponder many alternatives before making up my mind.

☐ 61. In discussions with people I often find I am the most dispassionate and objective.

☐ 62. In discussions I'm more likely to adopt a 'low profile' than to take the lead and do most of the talking.

☐ 63. I like to be able to relate current actions to a longer term bigger picture.

☐ 64. When things go wrong I am happy to shrug it off and 'put it down to experience'.

☐ 65. I tend to reject wild, spontaneous ideas as being impractical.

☐ 66. It's best to think carefully before taking action.

☐ 67. On balance I do the listening rather than the talking.

☐ 68. I tend to be tough on people who find it difficult to adopt a logical approach.

☐ 69. Most times I believe the end justifies the means.

☐ 70. I don't mind hurting people's feelings so long as the job gets done.

☐ 71. I find the formality of having specific objectives and plans stifling.

☐ 72. I'm usually one of the people who puts life into a party.

☐ 73. I do whatever is expedient to get the job done.

☐ 74. I quickly get bored with methodical, detailed work.

☐ 75. I am keen on exploring the basic assumptions, principles and theories underpinning things and events.

☐ 76. I'm always interested to find out what people think.

☐ 77. I like meetings to be run on methodical lines, sticking to laid down agenda, etc.

☐ 78. I steer clear of subjective or ambiguous topics.

☐ 79. I enjoy the drama and excitement of a crisis situation.

☐ 80. People often find me insensitive to their feelings.

Appendix F: Background questionnaire

Background Questionnaire for M206 Students

The whole questionnaire normally takes approximately 15 minutes, so you needn't linger over your answers. We value everything you have to say so please write as much as you can, adding comments if you wish. All responses will be treated in the strictest confidence. If you are completing this electronically just copy and paste this ✓ into either the appropriate box or beside the number that correspondents to your choice. For **YES/NO** answers just delete the one which **DO NOT** apply.

OU Personal ID Number

Gender
Male / Female

Age Range	***Please tick the box***
under 24	
25-29	
30-39	
40-49	
50-59	
60-64	
over 65	

PRIOR EXPERIENCE

1. How many years have you used a computer?

Years	*Please tick the box*
under 1	
1-5	
6-10	
11-15	
15-20	
Over 20	

2. What type of activities do you use the computer for?

Activities	*Please circle one*	*Do you use this for your work?*
Studying	*never* *everyday* 1 2 3 4 5	**Yes / No**
Playing computer games	1 2 3 4 5	**Yes / No**
Sending e-mail	1 2 3 4 5	**Yes / No**

Web browsing	1 2 3 4 5	Yes / No
Developing software	1 2 3 4 5	Yes / No
Developing databases	*never* *everyday* 1 2 3 4 5	Yes / No
Developing web sites	1 2 3 4 5	Yes / No
Developing computer graphics	1 2 3 4 5	Yes / No
Using a word processor	1 2 3 4 5	Yes / No
Using a spreadsheet	1 2 3 4 5	Yes / No
Using a database	1 2 3 4 5	Yes / No
Using business or specialised applications or packages	1 2 3 4 5	Yes / No
Other (*please comment*)	1 2 3 4 5	Yes / No

3. How would you characterise your own level of computer experience?

(Please circle one)

novice				*expert*
1	2	3	4	5

4. How do you like the information on web pages to be represented?

(Please circle one)

Pages with well-structured information such as tables and lists?	*not much* *a lot* 1 2 3 4 5
Pages with lots of visual representations such as graphics, photographs, and diagrams?	1 2 3 4 5
Pages with lots of text such as continuous prose?	1 2 3 4 5
A mixture of text and graphics?	1 2 3 4 5
A mixture of text and structured information?	1 2 3 4 5
A mixture of graphics and structured information?	1 2 3 4 5
A mixture of graphics, text and structured information?	1 2 3 4 5
Other (*please comment*)	1 2 3 4 5

5. Why do you write computer programs?

(Please circle one)

I don't write any
I write programs for fun
Its part of my job
Its part of a course of study
Other reason *(Please comment)*

6. Have you studied/used programming languages ? **Yes / No**

If YES, please complete the following table (*Tick the appropriate box*).

	under 1 year	1-5 years	6-10 years	11-15 years	15-20 years	over 20 years
Fortran						
Cobol						
Basic						
Ada						
Modula						
Pascal						
Visual Basic						
C or C++						
Smalltalk						
Java						
Prolog						
Lisp						
Other (*Please comment*)						

PRIOR KNOWLEDGE

7. Have you studied Data Types in programming languages? **Yes / No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

8. Have you studied Entity-Relationship Modelling? **Yes / No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

9. Have you studied operating systems? **Yes / No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

10. Have you studied Compilers? **Yes / No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Under graduate course*	*Post graduate course*	*Short training course*

EDUCATION AND EMPLOYMENT

11. Please tick the box(es) which correspond to your qualifications?

No formal qualifications	
CSE RSA School Certificate	
O Level/GCSE (1-4 subjects)	
O Level/GCSE (5 or more subjects)	
Professional qualification : less than A Level standard	
A level (1 subject)	
A level (2 or more subjects)	
ONC/OND/NVQ Level 2	
Professional qualification: less than degree	
HNC/HND/NVQ level 3	
Teachers Certificate	
University Diploma	
University 1st Degree	
Postgraduate degree	
Professional Qualification: degree or higher	
Other (*Please comment*)	

12. Please list your current and previous occupations, and how long you have worked in each one.

Current Occupation	*How many years*
Previous Occupation	
If you were employed less than 5 years in either occupation please list others	

STUDY MATERIALS

13. Please rate the following M206 materials in terms of how the information is presented and its usefulness.

Material	*Information Representation (Please circle one)*					*Usefulness (Please circle one)*				
	disliked				*liked*	*barely*				*very*
Chapter 1 An Object-oriented Approach	1	2	3	4	5	1	2	3	4	5
Chapter 2 Hard Questions, Soft Answers	1	2	3	4	5	1	2	3	4	5
Chapter 3 Using the Networks	1	2	3	4	5	1	2	3	4	5
Chapter 4 Object-oriented Applications	1	2	3	4	5	1	2	3	4	5
Chapter 5 Introduction to Human-Computer Interaction	1	2	3	4	5	1	2	3	4	5
Chapter 6 Object Concepts	1	2	3	4	5	1	2	3	4	5
Parsons & Oja Book	1	2	3	4	5	1	2	3	4	5
Course Map CD ROM	1	2	3	4	5	1	2	3	4	5
Object Shop CD ROM	1	2	3	4	5	1	2	3	4	5

14. Was the **frog** visualisation useful in helping you understand a Smalltalk program?	**Yes / No**

If YES, please state why?

15. If you have any comments about the M206 materials, in terms of how they helped you learn, please include them here.

Comments

ATTITUDES

16. Please rate how you feel about using computers?

(Please circle one)

intimidated				*masterful*
1	2	3	4	5

17. When you acquire a new application, what do you do first?

(Please circle one)

Install it and play with it?

Read the manual?

18. Please rate how you prefer the computer to list files on screen.

(Please circle one)

A simple list at the operating system level (such as in DOS)	*dislike* 1	2	3	4	*like* 5
A structured list as in Windows which display a structured list including details	1	2	3	4	5
A graphical representation such as the icons used in Windows with no details	1	2	3	4	5
Other (Please comment)	1	2	3	4	5

19. How would you best characterise yourself?

(Please circle one)

Theoretical	or	Practical?
Introvert Extrovert?	or	
A do-er	or	A thinker?
Methodical	or	Intuitive?

20. If you needed to have directions to a location what would you prefer?

(Please circle one)

A map?

A set of instructions?

21. If you recall from memory the directions to a location that you have previously visited, how do you best remember them?

(Please circle one)

A map?

A set of instructions?

22. How do you like the information in course units to be represented?

	(*Please circle one)*				
	not much				*a lot*
Pages with lots of text such as continuous prose?	1	2	3	4	5
Pages with lots of visual representations such as graphics, photographs, maps and diagrams?	1	2	3	4	5
Pages with well-structured information such as tables and lists, bullet points?	1	2	3	4	5
A mixture of text and graphics?	1	2	3	4	5
A mixture of text and structured information?	1	2	3	4	5
A mixture of graphics and structured information?	1	2	3	4	5
A mixture of graphics, text and structured information?	1	2	3	4	5
Other (*please comment*)	1	2	3	4	5

23. When you need to remember information, say for an exam, how do you recall the information?

	(*Please circle one)*				
	not usually				*mostly*
Verbally as: words, paragraphs, chunks of pages, stories, etc.?	1	2	3	4	5
Graphically as: mental pictures, mental maps, graphics, photographs, diagrams etc.?	1	2	3	4	5
Organised Information as: lists, tables, related points	1	2	3	4	5
A mixture of verbal and graphical?	1	2	3	4	5
A mixture of verbal and organised information?	1	2	3	4	5
A mixture of graphical and organised information?	1	2	3	4	5
A mixture of graphical, verbal and organised information?	1	2	3	4	5
Other (*please comment*)	1	2	3	4	5

If you wish to ask any questions about the evaluation, please contact **Linda Carswell**

by post:	by email	by telephone
Linda Carswell, Centre for Informatics Education Research, Faculty of Mathematics and Computing, Open University, Milton Keynes MK7 6AA	L.Carswell@open.ac.uk	**01908 65 26 96**

Don't forget to return the questionnaire either by email or in the pre-paid addressed envelope provided.

THANK YOU!

Background Questionnaire for Lecturers

The whole questionnaire normally takes approximately 15 minutes, so you needn't linger over your answers. We value everything you have to say so please write as much as you can, adding comments if you wish. All responses will be treated in the strictest confidence. If you are completing this electronically just copy and paste this ✓ into either the appropriate box or beside the number that correspondents to your choice. For **YES/NO** answers just delete the one which **DO NOT** apply.

Name

Gender
Male / Female

Age Range	***Please tick the box***
under 24	
25-29	
30-39	
40-49	
50-59	
60-64	
over 65	

PRIOR EXPERIENCE

1. How many years have you used a computer?

Years	***Please tick the box***
under 1	
1-5	
6-10	
11-15	
15-20	
Over 20	

2. How do you like the information on web pages to be represented?

(Please circle one)

	not much				*a lot*
Pages with well-structured information such as tables and lists?	1	2	3	4	5
Pages with lots of visual representations such as graphics, photographs, and diagrams?	1	2	3	4	5
Pages with lots of text such as continuous prose?	1	2	3	4	5
A mixture of text and graphics?	1	2	3	4	5

A mixture of text and structured information?	1 2 3 4 5
A mixture of graphics and structured information?	1 2 3 4 5
A mixture of graphics, text and structured information?	*not much* *a lot* 1 2 3 4 5
Other (*please comment*)	1 2 3 4 5

3. What programming languages have you used and for how long? (*Please tick the appropriate box*).

	under 1 year	1-5 years	6-10 years	11-15 years	15-20 years	over 20 years
Fortran						
Cobol						
Basic						
Ada						
Modula						
Pascal						
Visual Basic						
C or C++						
Smalltalk						
Java						
Prolog						
Lisp						
Other (*Please comment*)						

4. How many years have you been doing any of the following activities?

Activity	*under 1*	*1-5*	*6-10*	*11-15*	*15-20*	*over 20*
Teaching (in general)						
Teaching CS						
Working in a CS related occupation						
Working in a non-CS related occupation (Please comment)						
Writing learning materials						
Writing CS learning materials						

5. What do you feel is the best example of you development of CS learning materials (e.g. M301, unit 13), and why?

PRIOR KNOWLEDGE

6. Have you taught Data Types in programming languages? **Yes /No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

7. Have you taught Entity-Relationship Modelling? **Yes /No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

8. Have you taught operating systems? **Yes /No**

If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Undergraduate course*	*Postgraduate course*	*Short training course*

9. Have you taught Compilers? If YES, briefly describe the course and tick the box corresponding to the level of the course.

Course Description	*Please tick the appropriate box*				
	ONC/OND GNVQ level 2	*HNC/HND GNVQ level 3*	*Under graduate course*	*Post graduate course*	*Short training course*

CAREER BACKGROUND

10. Please list your current and previous occupations, and how long you have worked in each one.

Current Occupation	*How many years*
Previous Occupation	
If you were employed less than 5 years in either occupation please list others	

STUDY MATERIALS

11. Have you encountered the **frog** visualisation in M206?	**Yes / No**
If YES, please state how useful you think this is for students in helping them to understand a Small talk program.	

ATTITUDES

12. When you acquire a new application, what do you do first?

(Please circle one)

Install it and play with it? Read the manual?

13. Please rate how you prefer the computer to list files on screen.

	(Please circle one)				
	dislike				*like*
A simple list at the operating system level (such as in DOS)	1	2	3	4	5
A structured list as in Windows which display a structured list including details	1	2	3	4	5
A graphical representation such as the icons used in Windows with no details	1	2	3	4	5
Other (Please comment)	1	2	3	4	5

14. How would you best characterise yourself?

(Please circle one)

Theoretical	or	Practical?
Introvert Extrovert?	or	
A do-er	or	A thinker?
Methodical	or	Intuitive?

15. If you needed to have directions to a location what would you prefer?

(Please circle one)

A map?
A set of instructions?

16. If you recall from memory the directions to a location that you have previously visited, how do you best remember them?

(Please circle one)

A map?
A set of instructions?

17. How do you like to represent the information in course units?

	(Please circle one)				
	not much				*a lot*
Pages with lots of text such as continuous prose?	1	2	3	4	5
Pages with lots of visual representations such as graphics, photographs, maps and diagrams?	1	2	3	4	5
Pages with well-structured information such as tables and lists, bullet points?	1	2	3	4	5
A mixture of text and graphics?	1	2	3	4	5
A mixture of text and structured information?	1	2	3	4	5
A mixture of graphics and structured information?	1	2	3	4	5
A mixture of graphics, text and structured information?	1	2	3	4	5
Other (*please comment*)	1	2	3	4	5

18. When you need to remember information how do you recall it?

	(Please circle one)				
	not usually				*mostly*
Verbally as: words, paragraphs, chunks of pages, stories, etc.?	1	2	3	4	5
Graphically as: mental pictures, mental maps, graphics, photographs, diagrams etc.?	1	2	3	4	5
Organised Information as: lists, tables, related points	1	2	3	4	5
A mixture of verbal and graphical?	1	2	3	4	5
A mixture of verbal and organised information?	1	2	3	4	5
A mixture of graphical and organised information?	1	2	3	4	5
A mixture of graphical, verbal and organised information?	1	2	3	4	5
Other (*please comment*)	1	2	3	4	5

If you wish to ask any questions about the evaluation, please contact me

L.Carswell@open.ac.uk

Tel Ext 52696

Many Thanks!!!

Linda Carswell

Appendix G: Pre and Post-tests for Study 1

Study 1 - Pre-Test

Name: ______________________________

PI Number: ___________________________

The following questions are just to give us an idea about what you already know. You are not expected to know all the answers to these questions so don't worry if you can't solve them all. Brief answers will be fine. If you are not sure of the answer write whatever you can, it is all very valuable information for our research.

Entity-Relationship Modelling

1. What type of application is Entity-Relationship Modelling typically used for developing?

2. What is the purpose of Entity-Relationship modelling?

Compiler

3. What is the main purpose of a compiler?

4. Name one type of check that a compiler performs.

Concurrency

5. Name one way of preventing two people from reading and writing to the same file at the some time?

Data Types

6. Why do we explicitly need to state what data type we are using when defining a variable?

Study 1 – Post -Test

Name:____

PI Number:____________________________________

The following questions are just to give us an idea about what you may have picked up from the learning materials. You are not expected to know all the answers to these questions so don't worry if you can't solve them all. Brief answers will be fine. If you are not sure of the answer write whatever you can, it is all very valuable information for our research.

Entity-Relationship Modelling

3. What type of application is Entity-Relationship Modelling typically used for developing?

4. What is the purpose of Entity-Relationship modelling?

5. Use an example you have seen in the learning materials to illustrate entity-relationship modelling.

Compiler

4. What is the main purpose of a compiler?

5. Name one type of check that a compiler performs.

5. Use an example you have seen in the learning materials to illustrate how a compiler works.

Concurrency

6. Name one way of preventing two people from reading and writing to the same file at the some time?

6. Use an example you have seen in the learning materials to illustrate how this might work.

Data Types

7. Why do we explicitly need to state what data type we are using when defining a variable?

8. Use an example you have seen in the learning materials to illustrate how the computer treats different data types.

Appendix H: Additional Results

Are the preferences expressed for representations independent, i.e. if a participant chooses one type of representation in one topic, will they choose the same type of representation in another topic?

Chi-Square was used to check if the choices made on representation can be treated as independent measures. I.e. if a participant choices a representation in one topic area, will they choose the same representation in another topic area?

If participants choose one type of representation in the E-R Modeling topic, will they choose the same type of representation in the Compiler topic?

Table H.1: E-R Modeling Representation Choice * Compiler Representation Cross Tabulation

			Compiler Representation Choice			
			structured text	graphics	mixed	
E-R Modelling Representation Choice	structured text	Count		1		1
		% within E-R		100.00%		100.00%
	graphics	Count	3	7	3	13
		% within E-R	23.10%	**53.80%**	23.10%	100.00%
	mixed	Count	1	5	2	8
		% within E-R	12.50%	62.50%	**25.00%**	100.00%
	Total	Count	4	13	5	22
		% within E-R	18.20%	59.10%	22.70%	100.00%

Table H.2: E-R Modeling Representation Choice * Compiler Representation Chi-Square

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.101[a]	4	.894
Likelihood Ratio	1.466	4	.833
Linear-by-Linear Association	.161	1	.688
N of Valid Cases	22		

a. 8 cells (88.9%) have expected count less than 5. The minimum expected count is .18.

There is no evidence that relationship between the choice of representation they would make for the E-R topic and the Compiler topic is not independent. While 53% of who chose a graphical representation for E-R Modelling would choose a graphical representation for the Compiler representation, the percentages for those who would make the same choice for other representations in the Compiler topic as the E-R Topic is below 50%.

If participants choose one type of representation in the E-R Modelling topic, will they choose the same type of representation in the Concurrency topic?

*Table H.3: E-R Modeling Representation Choice * Concurrency Representation Choice Crosstabulation*

			Concurrency Representation Choice				
			text	structured text	graphics	mixed	
E-R Modeling Representation Choice	structured text	Count			1		1
		% within E-R			100.00%		100.00%
	graphics	Count	1	1	4	7	13
		% within E-R	7.70%	7.70%	30.80%	53.80%	100.00%
	mixed	Count			3	4	7
		% within E-R			42.90%	57.10%	100.00%
	Total	Count	1	1	8	11	21
		% within E-R	4.80%	4.80%	38.10%	52.40%	100.00%

*Table H.4: E-R Modeling Representation Choice * Concurrency Representation Chi-Square*

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.021[a]	6	.806
Likelihood Ratio	3.929	6	.686
Linear-by-Linear Association	.722	1	.396
N of Valid Cases	21		

a. 11 cells (91.7%) have expected count less than 5. The minimum expected count is .05.

There is no evidence that relationship between the choice of representation they would make for the E-R topic and the Concurrency topic is not independent. While 57% of who chose a mixed representation for **E-R Modelling** would choose a graphical representation for the **Concurrency** representation, the percentages for those who would make the same choice for other representations both topics is below 31%.

If participants choose one type of representation in the E-R Modelling topic, will they choose the same type of representation in the Data Types topic?

*Table H.5: E-R Modeling Representation Choice * Data Types Representation Choice Crosstabulation*

			Data Types Representation Choice				
			text	structured text	graphics	mixed	
E-R Modeling Representation Choice	structured text	Count		1			1
		% within E-R Modeling		100.00%			100.00%
	graphics	Count	1	4	1	7	13
		% within E-R Modeling	7.70%	30.80%	7.70%	53.80%	100.00%
	mixed	Count		3	1	4	8
		% within E-R Modeling		37.50%	12.50%	50.00%	100.00%
	Total	Count	1	8	2	11	22
		% within E-R Modeling	4.50%	36.40%	9.10%	50.00%	100.00%

*Table H.6: E-R Modeling Representation Choice * Data Types Representation Chi-Square*

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.680[a]	6	.848
Likelihood Ratio	3.264	6	.775
Linear-by-Linear Association	.382	1	.536
N of Valid Cases	22		

a. 11 cells (91.7%) have expected count less than 5. The minimum expected count is .05.

There is no evidence that relationship between the choice of representation they would make for the E-R topic and the Data Types topic is not independent. While 100% chose a structured text representation for E-R Modelling would choose a structured text representation for the Data Types representation, it only represents one occurrence. The percentages for those who would make the same choice for mixed representation in both topics is 50% and for other representations are below 10%. As the structured text figure represents only one case it is unlikely to be significant.

If participants choose one type of representation in the Compiler topic, will they choose the same type of representation in the Concurrency topic?

Table H.7: Compiler Representation Choice * Concurrency Representation Choice Crosstabulation

			Concurrency Representation Choice				
			text	structured text	graphics	mixed	
Compiler Representation Choice	structured text	Count	1		2	1	4
		% within Compiler	25.00%		50.00%	25.00%	100.00%
	graphics	Count		1	5	7	13
		% within Compiler		7.70%	**38.50%**	53.80%	100.00%
	mixed	Count			1	3	4
		% within Compiler			25.00%	**75.00%**	100.00%
	Total	Count	1	1	8	11	21
		% within Compiler	4.80%	4.80%	38.10%	52.40%	100.00%

Table H.8: Compiler Representation Choice * Concurrency Representation Chi-Square

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.163[a]	6	.405
Likelihood Ratio	5.677	6	.460
Linear-by-Linear Association	3.088	1	.079
N of Valid Cases	21		

a. 11 cells (91.7%) have expected count less than 5. The minimum expected count is .19.

There is no evidence that relationship between the choice of representation they would make for the **Compiler** topic and the **Concurrency** topic is not independent. While 75% of who chose a mixed representation for Compiler topic would choose a mixed representation for the Concurrency topic, the percentages for those who would make the same choice for other representations in the Compiler topic as the Concurrency Topic is below 39%.

If participants choose one type of representation in the Compiler topic, will they choose the same type of representation in the Data Types topic?

Table H.9: Compiler Representation Choice * Data Types Representation Choice Crosstabulation

			Data Types Representation Choice			
			structured text	graphics	mixed	
Compiler Representation Choice	structured text	Count	3	1		4
		% within Compiler	75.00%	25.00%		100.00%
	graphics	Count	4		8	13
		% within Compiler	30.80%		61.50%	100.00%
	mixed	Count	1	1	3	5
		% within Compiler	20.00%	20.00%	60.00%	100.00%
	Total	Count	8	2	11	22
		% within Compiler	36.40%	9.10%	50.00%	100.00%

Table H.10: Compiler Representation Choice * Data Types Representation Chi-Square

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.211[a]	6	.223
Likelihood Ratio	10.880	6	.092
Linear-by-Linear Association	2.508	1	.113
N of Valid Cases	22		

[a] 11 cells (91.7%) have expected count less than 5. The minimum expected count is .18.

While there appears to be a relationship between the choice of representation in these two topics, it only holds for a structured text representation and a mixed representation. It does not hold for the graphics representation. There is no evidence that relationship between the choice of representation they would make for the **Compiler** topic and the **Data Types** topic is not independent.

If participants choose one type of representation in the Concurrency topic, will they choose the same type of representation in the Data Types topic?

*Table H.11: Concurrency Representation Choice * Data Types Representation Choice Crosstabulation*

			Data Types Representation Choice				
			text	structured text	graphics	mixed	
Concurrency Representation Choice	text	Count		1			1
		% within Concurrency		100.00%			100.00%
	structured text	Count				1	1
		% within Concurrency				100.00%	100.00%
	graphics	Count		2	1	5	8
		% within Concurrency		25.00%	**12.50%**	62.50%	100.00%
	mixed	Count	1	5	1	**4**	11
		% within Concurrency	9.10%	45.50%	9.10%	**36.40%**	100.00%
	Total	Count	1	8	2	10	21
		% within Concurrency	4.80%	38.10%	9.50%	47.60%	100.00%

*Table H.12: Concurrency Representation Choice * Data Types Representation Chi-Square*

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.797[a]	9	.852
Likelihood Ratio	5.802	9	.760
Linear-by-Linear Association	.281	1	.596
N of Valid Cases	21		

a. 15 cells (93.8%) have expected count less than 5. The minimum expected count is .05.

There is no evidence that relationship between the choice of representation they would make for the **Concurrency** topic and the **Data Types** topic is not independent. The percentages for those who would make the same representation choice in the Concurrency topic as the Data Types Topic is below 37%.

To conclude, there is no evidence to suggest that the choice of representation in any of the topics is not independent of the choice in another topic. Subsequently it is feasible to treat the choices made on all four topics by individuals as independent measures.

Student Group

What are the verbatim constructs and cards in the Visual/Text Construct?

Within the superordinate construct *Representation style* all student constructs that had verbatim or gist agreement that described a card as either containing graphics or text was totalled in a frequency table.

Table H.13: Visual/ Text – Students

Graphics	***Card Numbers***	***Text only***	***Card Numbers***
Graphical	2, 11, 13	Mainly text	1, 3, 4, 16
Diagrams	2, 4, 5, 7, 8, 11, 12, 13,	Text based	1, 3, 6, 14, 16
Diagrammatic	5, 7, 8, 12,	Other/textual	1, 6, 12, 14, 15,16,
Most graphic	2, 4, 11, 13	Text	1 ,3, 6, 14, 16
Flow diagrams	2, 5, 7, 11, 12	Textual	1, 3, 6, 14, 16
Diagram explanations	4, 8, 13	Pure text	1, 3, 6, 14, 16
Pictorial	2, 7, 11, 13	Purely text	1, 3, 6, 14, 16,
Graphics	2, 4, 5, 7, 8, 11, 12, 13	Volumes of text	1, 3, 14, 16
Text/Graphics mix	2, 4, 5, 7, 8, 11, 13	Text	1, 3, 14, 16
Flowcharts/Flowchart type graphics	2, 7 ,5, 11, 4		
Funky flowcharts with person	13		
Semi-pictorial	5, 7, 8, 12		
Pictorial	2, 4, 13, 11		
Heavy use of graphics	2, 15, 13		
Element of tables and/or numbered lists but always graphics	4, 11, 12		

What are the verbatim constructs and cards in the Easy/Hard Construct?

The card which appears in all categories of 'easy of understanding' is 12, with 2, 11 and 13 being in 3 of these categories. Card 12 is a mixed representation and contains graphical components and the other cards are graphical representations also containing graphical components.

Table H.14: Easy/Hard – Students

Groups	Card numbers	Groups	Card numbers
Easiest	6, 7, 11, 12, 14, 15	Tough	1, 3, 9, 13
Easy	2, 5, 11, 12, 13,	Hard	1, 3, 6, 14, 16
Easier to understand	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16,	Not easy to understand	1, 3 ,14
Easiest	2, 4, 12, 13,	Most difficult - lots of text and lots of reading - longer to do	1, 3, 14, 16,

What are the verbatim constructs and cards in the Like/Dislike Construct?

Within the superordinate construct Accessibility the sorts that referred liked and disliked with either verbatim or gist agreement were put into a frequency table as follows.

Table H.15: Like/Dislike – Students

Like	*Card Numbers*	*Dislike*	*Card Numbers*
Best: I like the most	2, 4, 5, 13,	Don't like	1, 3, 4, 6, 8, 16,
Like to study these	4, 10, 11, 12, 13, 15	Definitely not like to have to read	1, 14, 16
Best	2, 4, 9, 12	4th Best	1, 3, 14, 16
Very creative, Imaginative, presentation is attractive	2, 7,11, 13	Pretty boring	1, 3, 6, 14, 16,
Not so dreadful	4, 5, 7, 10, 11, 12, 13, 15,	Dreadful	1, 2, 3, 6, 8, 9, 14, 16,
What I'd like	1, 4, 5, 6, 7, 8, 10, 11,12, 14, 16	Poor impression	2, 3, 9, 13, 15,
Best preferred	5, 7, 11, 13	Least	1, 3 ,6, 14, 16
Appeals most	7, 9, 11, 12, 13	Least prefer	1, 3, 6, 14, 16,
Best: most pictures	2, 4, 11, 13	Worst	1, 3, 14, 16
Best	2, 4, 12, 13,	The way I would not like it presented	1, 3, 6, 9, 10, 14, 15, 16

What are the verbatim constructs and cards in the Introductory/Deeper Construct?

Verbatim and gist agreement constructs for introductory material and further reading were summaries in a frequency table, as follows.

Table H.16: Introductory/Deeper Reading – Students

Introductory material	*Card numbers*	*Deeper Reading*	
Better for 1st reading	4, 5, 6, 7, 8, 10, 11, 12, 13	Reading for further understanding	1, 3, 4, 6, 8, 14, 16
1st reading: introduction looks nice from starting point of view	1, 5, 6, 10, 16,	Deep Reading	1, 2, 3, 6, 13, 14, 16
Introduction	4, 5, 7, 8, 11, 12		
Basic introduction: 1st sentence does not rely on the knowledge of the reader	5, 8, 12, 15, 16,		
Introductory	2, 5, 7, 11, 12,, 13,		
Main Information: First time	3, 9, 14, 16		
1st reader - less experienced	1, 4, 6, 7, 8, 13, 14, 16,		

What are the verbatim constructs and cards in the Not so Dense/Dense Construct?

Within the volume superordinate construct verbatim or gist agreement construct are summarised in the following table.

Table H.17: Not so Dense/Dense – Students

Not so dense/not too much information	***Card numbers***	***Dense/Lots of information***	***Card numbers***
Little - for people who don't need to know a lot, just pick out core points	2, 5, 13	Lots - quite a lot of detail	1, 3 ,6, 9, 14 ,16
Less information to take in	2, 5, 12	Dense (Stay away from)	1, 3, 4, 6, 14, 16,
Not so dense	4, 5, 13	Dense	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16
Very little text & lots of graphics	2, 5, 9, 13	Loads of text in it	1, 3, 6, 7, 8, 11, 14, 16
Least	2, 5, 11, 13	Most	1, 3, 4, 6, 8, 9, 14, 15, 16,
Two-thirds full	1, 5, 14,	All the way to the bottom	4, 7, 8, 9, 11, 12,
Least info	4, 5	Most information	3, 9, 14, 16,
Least Dense	2, 5, 13	Too much	3, 8, 9
		Most Wordy	3, 7, 8, 9

Table H.18: Definition of Students Constructs Using the Laddering Technique

Construct	***Definition of Construct gleaned from laddering exercise***
Like-Dislike	What I liked best. This is the visual layout rather than content. Less on page is easier to get a visual view, less off-putting. Prefer diagrams. I like an example to hit me - to stand out from the text. The perfect document has an overview/objectives, brief descriptions in the text followed by diagrams, then the concluding diagram, which has been built upon section by section. Liked Best: doesn't look like it has too much text. Like shading, like graphics. A graphic is better than having a table with all the heavy lines. Best: Aesthetically pleasing. A combination of things. The text must be clear and not like a book. It should have tables and some pictures interchanging between text and graphics. How attractive the presentation is. Very creative and imaginative, presentation is attractive. What I like is inviting. Inviting is easy to understand, more white space, good mix and variety. *Uninviting is small text and table in general, too many diagrams, things that are cramped together, inconsistency - a little bit in a line and then a big bit in a line, doesn't look very easy to understand. Appeals most: Like graphics but sometimes pictures don't explain everything. Text and graphics - best of both. 50-50 but would lean towards more graphics. Don't like cartoons. Best Preferred: Graphics supported by text. Max of 2 graphics per page plus text. Text spacing. Font size - minimum should be 10 point. Well spaced paragraphs with lines in-between. Prefer to read 2 columns per page - length of line is shorter, particularly on computer screens My preferences. Clear, nice layout, section headings - not a straight block of text. Looks interesting to the eye. A page of text is dull. Some of them are also like what I see at work and that helped. Dreadful: all words - nothing else. No gaps - a load of dribble with no breaths.
Easy-Hard	Easy: lots of paper, lots of space. Even though it may have lots of words as long as there is white space it is better than too much/too large a graphic. Easiness of understanding the examples provided. Dense is difficult to read and difficult to go back over. Whereas tables are more difficult to understand initially but are later good for reference. Easy to understand is:-*text with headings * easy text summarized with tables *but difficult concepts are added with a diagram. Whether it has simple sentence construction, consistency, and is difficult to read.

	Difficult: not what you'd want to read in the first place. Too much text - boring. You have to read a line at a time - you can't skim read. Words in bold require work. Graphics not supporting text giving information.
Introductory-Deeper Reading	Whether the document is suitable for introductory, further understanding or reference/straight revising.
Not Dense-Dense	Lots of information - lots of text. Little information conveys little to the reader. Density is lots and lots of text. Not dense is a mixture of graphics and reading. Preference for the "Not quite as dense group" Density is lots of text on page. Lots of words are claustrophobic. 16 looks more dense that Representation style because of layout. Worked examples look less off-putting. How much text the document has. General appearance. Words seem to have more volume than graphics. However an arrow can mean more. How much of the page it takes up. Text is lots of volume. E.g. like a book - few paragraphs. It doesn't throw you as much if it has graphics, tables and text. Quite a lot on the sheet. A lot of black ink on the sheet. A lot of black - darker sheet of paper. Least information is a sheet with more white space on it. Words on the page.

Academic Group

What are the verbatim constructs and cards in the Visual/Text Construct?

Within the superordinate construct *Representation style* all academic constructs that had verbatim or gist agreement that described a card as either containing graphics or text was totalled in a frequency table (for a more detailed look at the actual constructs and the card numbers in appendix X)

Table H.19: Visual/ Text – Academics

Visual (graphical) components	***Card Numbers***	***Text***	***Card Numbers***
Other graphical and visual organisation	2, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15	All Text	1, 3, 6, 14, 16
Acceptable diagrams	4, 7, 8, 13	Not Acceptable (awful)	2, 5, 11, 12, 15
Diagrams	2, 4, 5, 7, 8, 11, 12, 13	No Diagrams	1, 3, 6, 9, 10, 14, 15, 16
Diagrammatic representations	2, 5, 7, 11,13	Primarily text	1, 3, 4, 6, 8, 14, 16
Graphics	2, 5, 7, 8, 10, 11, 12, 13	Non graphics	1, 3, 4, 6, 9, 14, 15, 16
Graphics	2, 4, 5, 8, 7, 11, 12, 13	Plain text	1, 3, 6, 14, 16
Diagrams	2, 4, 5, 7, 11, 13	Text	1, 3, 6, 14, 16

What are the verbatim constructs and cards in the Like/Dislike Construct?

The superordinate accessibility construct was examined for academics verbatim and gist agreement in constructs relating to their like or dislike of the materials.

Table H.20: Like/Dislike – Academics

Like	Card Numbers	Dislike	Card Numbers
Like best (initial glance)	7, 10, 13, 11	(the rest)	1, 2, 3, 4, 5, 6, 8, 9, 12, 14, 15, 16
Interesting	12, 11, 10, 5, 7, 2, 13	Boring	9, 4, 15, 3, 16, 6, 14, 1
Inviting me to look	5, 13, 7, 11, 12, 4	Impenetrable	1, 2, 3, 6, 8, 9, 10, 14, 15, 16
Want to read	3, 1, 13, 5, 6, 16, 7, 4, 8, 15, 10, 11, 12	Don't want to read	9, 14, 2

What are the verbatim constructs and cards in the Like/Dislike Construct?

The superordinate accessibility construct was examined for academics verbatim and gist agreement in constructs relating to level of difficulty of the materials.

Table H.21: Easy/Hard – Academics

Easy	Card Numbers	Hard	Card Numbers
Accessible, inviting me to look	4, 5, 7, 11, 12, 13,	Impenetrable	1, 2, 3, 6, 8, 9, 10, 14, 15, 16
Straight text	1, 3, 6, 14, 16	Complicated information being displayed	2, 8, 9, 12, 13

What are the verbatim constructs and cards in the Introductory/Deeper Reading Construct?

The academic constructs were examined for verbatim and gist agreement in relating to level of reading of the materials.

Table H.22: Introductory/Deeper Reading – Academics

1st reading	*Card Numbers*	*Deeper Reading*	*Card Numbers*
1st reading	2, 5, 11, 12, 13	The rest	1, 3, 4, 6, 7, 8, 9, 10, 14, 15, 16
Introduction	14, 7	Aren't good for introduction or revision	1, 2, 3, 4, 5, 8, 9, 16
Better for 1st reading	4, 5, 6, 7, 8, 10, 11, 12, 13	Detailed reading	1, 2, 3, 9, 14, 15, 16
1st reading	1, 5, 6, 10, 16	Not for starters	2, 3, 4, 7, 8, 9, 11, 12, 13, 14, 15
Basic introduction	5, 8, 12, 15, 16	Sophisticated	1, 2, 3, 4, 6, 7, 9, 10, 11, 13, 14
1st reader – less experienced	1, 4, 6, 7, 8, 13, 14, 16	2nd reading – complex	2, 3, 5, 9, 10, 11, 13, 15

What are the verbatim constructs and cards in the Not so Dense/Dense Construct?

The academic constructs were examined for verbatim and gist agreement in relating to volume of information.

Table H.23: Not so Dense/Dense – Academics

Not so dense	***Card Numbers***	***Dense***	***Card Numbers***
Lesser information	1, 5, 9, 14	Greater Information	2, 3, 4, 6, 7, 8, 10, 11, 12, 13, 15, 16
Lest amount of text – more inviting	1, 5, 14	Most difficult to read	2, 3, 4, 6, 8, 13, 16
Acceptable (amount on page)	1, 2, 4, 6, 7, 10, 11, 12, 13, 14, 15	Not acceptable	3, 5, 8, 9, 16
Not much on the page	1, 6, 14	Lots on the page	2, 3, 8, 9, 11, 12, 13, 15
Not dense	1, 4, 5, 6	Very dense	2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16

Table H.24: Definition of Academics Constructs Using the Laddering Technique

Construct	Definition of Construct gleaned from laddering exercise
Like	Using diagrams - a diagram gives a lot easily. First impression is - very friendly. Uses progressive teaching. Can learn a lot without reading too much How much interest it would generate for the reader Inviting is white space - not filling the whole page. Attractive. Don't use lines in tables unless strictly necessary. Don't use uppercase - that's shouting. However bold can say "I can help you". Shading can be useful. More about what I didn't want to read. Not so much the topic - but small fonts, busy diagrams using lots of arrows, everything close together, taking up margin space. Don't use lines in tables unless strictly necessary. Don't use uppercase - that's shouting.
Dislike	A style that makes you not want to read. Such as small fonts, busy diagrams using lots of arrows, everything close together, taking up margin space.
Easy	Complexity is " a hell of a lot of information being put across". Diagrams can also be complex as there are indeterminate ways of reading it. A diagram in itself is not very good, but used with labels and text they complement each other.
Hard	
Introductory	Used to convey important points to the 1st time reader - show me quickly. Don't overwhelm me, direct me to the important information. Introduction material is good for 1st reading. Sets out something that motivates - the scenario- encourages the student to come on board as opposed to "its good for your soul - just learn it" This is a first reading for someone who doesn't know anything about the topic. Introductory materials should include bullet points for overview, or diagrams, or an example to show what the concept is. An example can show why it is necessary and why it is useful Whether it is suitable for starters. Whether it's a basic introduction or is more sophisticated relying on some experience 1st reader less experienced, 2nd time reader will have some knowledge
Deeper Reading	
Not Dense	Acceptable - Text, headings, tables, graphics - a variety of types of object on the page. Different types of layout of space, weight of items - bold italics.... But not too much as in 10. The prettiest page is 13 - different types: typefaces, bold different shapes

Dense	How much information is on the page Density is a lot on the pages, lots of diagrams e.g. 3 diagrams. The route through is not very clear. Dense is a lot of black on the page - like Springer-Verlag books. Not so dense is white space, wide margins, interlying gaps. Don't wnat to physically scan with my eyes

Table H.25: Details of incidental learning pre and post tests

Name	*Incidental learning?*	*Traceable to?*	*Example Origin type*	*Student example type*
Jen Abley	**E-R modelling** **YES.** Picked up something on databases sorting	Not traceable.		
	Compiler **YES.** Picked up *2 key words* but they are used in each of the documents – although the phrasing is slightly different – not readily traceable to any document.	Not easily traceable		
	Concurrency **YES.** In post-test specifically uses the term **locking**. Example used is banking	No **2** seems a reasonable assumption as it is specifically a banking system, the others are loosely banking/financial	Graphical	Textual
	Data Types **YES.** Uses specific terms in post test – *Integer* and *Character*	Origin not clear		
James Albiston	**E-R modelling** **YES.** Post test shows a change in language	Not easily traceable but **12** look contains some of the design models he refers to.	Graphical	Textual

	Compiler **YES.** Picks up a key term only evident in **13**	* Very clearly traceable to **13**	Graphical	Graphical – he replicates the 2nd diagram in 13 including some of the icons and their labels (i.e. very specifically the little man representing a programmer),
	Concurrency **UNCLEAR.** Post-test shows a change to more specific language.	The language loosely corresponds to the process illustrated in 2	Graphical	Text
	Data Types **YES.** Language becomes more specific. The example he quotes is a correct usage but not directly from the topic area (i.e. he quotes an example from compilers)	* Very clearly to **13**	Graphical	Reports a program fragment, including what the language was.
Jacqueline Chelin	**Data Types** **YES.** But only remembered one thing –"to differentiate between Integers and ??"	Unclear		
Andy Day	**NO.** Nothing			
Paul Day	**E-R modelling** Language slightly more specific	The example is a graphical representation but the scenario comes from a textual representation. Probably prior knowledge as this student was quite knowledgeable.	Graphical/ Text	Graphical
	Concurrency **NO.** His example more	Not easily attributable.	Graphical	Graphical

	closely matches the point at which locking is initiated – i.e. on a read as opposed to a write.	However **2** is the only one that shows that the record locking occurs on a read.		
Nick Edelsten	**E-R modelling** **YES.** More specific language used. Quotes an appropriate example from Concurrency. The diagram uses icon from **2**	Attributable to **2**	Graphical	Graphical
	Data Types **YES.** Some incidental learning – re illegal calls where an integer is expected	Not attributable		
Andrew Goldsmith	**E-R modelling** **NO.** Language becoming more specific.	Not attributable		Graphical
	Compiler **YES.** Language changes very specifically to use terms in **13** and **5**	The diagram resembles **5** in origin and uses labels from **13**	Graphical and Mixed	Graphical
	Concurrency **NO.** Same	Diagram bears some relationship to **2**	Graphical	Graphical
	Data Types Very specific change in language – uses language from the cards which he did not use before (although he claims not to have read them).	Not attributable		
Wanda Hall	**E-R modelling** **YES** Specific and concise change of language. The example quoted is from **11** – graphical representation	Provides a structured representation on a graphical example from **11**	Graphical	Structured (shows file structure which is shown as shaded

	Compiler **YES.** Explanation is more precise. Example resembles one used in **5**. However she has interpreted it into her own model. E.G where we had actual code she writes "Words written in code". And where binary is used in the diagram she correctly labels it "machine code"	Example is similar to **5** but she interprets the text in the diagram and gives it a label.	Mixed	Graphical
	Data Types YES. **Accurate answer – compared to the pre-test**	Not obvious		
Brian Hodgson	**NO.** He states that he did not read the materials in sufficient detail in order to provide answers on the post-test.			
Natasha Howlett	**NO.** The post-test reflected the pre-test. And where, in the pre-test she had answered in the post-test she wrote "as before".			
Dinah Richards	**E-R modelling** YES. Uses text to refer to examples. One is example is from E-R modelling – **11** and the other is from a bank account and balance **2** – which is an inappropriate reference, but obviously something she remembered.	From **11** (and **2**?)	Both examples are graphical	Textual
	Data Types **NO.** But remember **8** and **4** as parity diagrams	From **8** and **4**	Graphics and mixed	Textual
Penny Tymon	**E-R modelling** **NO** – Same. However the example she quotes is from **12.**	From **12** - directly	Graphical	Textual
	Compiler **YES** – picked something up – and uses the term variables which can possibly be attributed to 13	**13**	Graphical	Textual

	Concurrency **NO.** But the example quoted is directly attributable to 14	**14**	Text only	Textual
	Data Types YES. Quotes an example (not inappropriately) form Data Types and uses terms in **10.**	**10**	Structured text	Textual

Appendix I: Study Materials for Study 2

Study 2 – Experiment Guidelines for Participants

You will be given a set of learning materials that we are going to ask you to study. You can make notes on the paper provided and you can also write on the materials themselves. Your will be given approximately **30 minutes** to read the materials (but if you need longer, please ask for more time).

The purpose of this experiment is to **test the materials** – not to test you the student. After you have read the materials we will be giving you some post-tests, which will take approximately 55 minutes. These are to help us understand how well the materials have helped you understand new concepts.

All of your responses will be treated with **strict confidence.**

Dealing with multiple processes: resource management

As a child I always wanted my own television set. Today, I suspect that the majority of children have their own. Many households therefore have 2, 3 or even more televisions. Conversely you don't see many households with more than one oven. So what is it about televisions that makes people want one each?

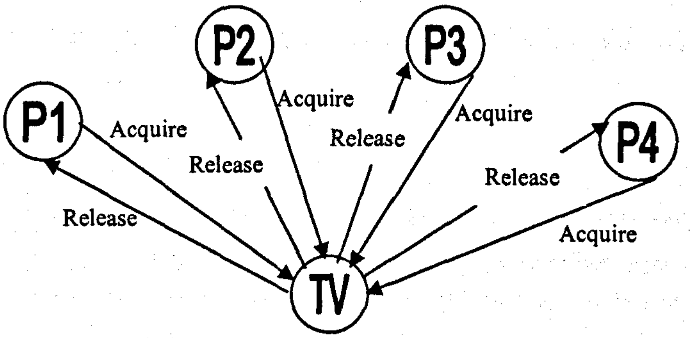


Figure 1, a model of several people wanting to use a shared resource for different purposes

A single television can only show one channel's programme at a time. In a single television home, with something good showing - a blockbuster film perhaps - everyone will be happy to watch it. Figure 1 illustrates how a person, in the diagram shown as either P1, P2, P3 or P4, must wait to gain control of the television in order to choose the channel they want to watch if everyone wants to watch something different. If the single television home is also a single video home as well it may be possible, if the potential viewers are flexible, to negotiate an agreement in which one watches in real-time and the other records. That's not always a perfect solution however as perhaps both wanted to record a programme!

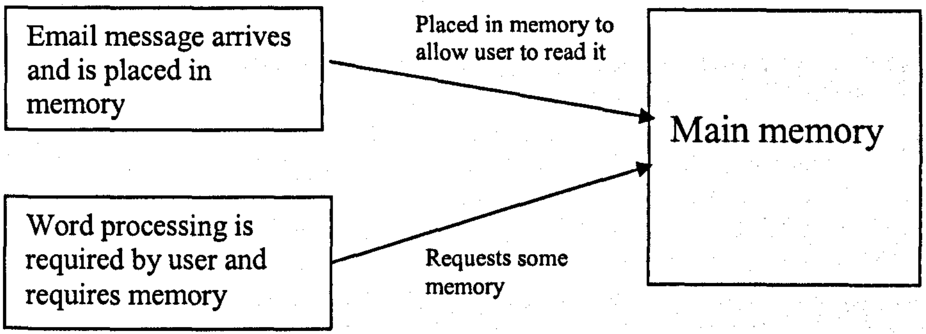
Review Question 1

Why might a household want to have several television sets but not several ovens?

One television is required if both parties want to watch the same program. One television and one video are required if one party can be convinced to record a programme while the other watches. Two televisions will be required if both parties want to watch what they want immediately. Two videos will be required if both want to record for later. It's a problem of resources and resource management.

It's the same with computers: two processes that want to use the same resource may be able to without problem. Either their uses will be compatible and they can make do with one copy, or users will 'negotiate' who gets to use the single copy first, and in which way.

For example in a single user computer system, (such as the PC that most of us use), when an email message arrives, the operating system needs to set aside space in the computer's memory to hold it. But at the same time, the user could decide to create a new document in her word processing application that also needs some memory allocated to it.



If memory allows access to the word processing request then the email message will be lost

Figure 2, illustrating the problem when two processes want the same resource at the same time

As figure 2 illustrates, the operating system has to negotiate between competing requests such that the email message isn't wiped out by the new document (or vice versa). If the negotiation isn't done correctly, and the OS first assigns space to the email message then the same space to the new document, the email message will effectively be lost when it is overwritten in memory. This is called **destructive interference.**

In computer operating systems processes need to negotiate for the use of resources such as space in memory, or use of a printer. Today, understanding of the techniques for negotiation is almost complete (though they still cause problems when put into practice!). Originally this was anything but the case: the operation of computing systems involving multiple processes was rather a hit and miss affair. To solve the problems, solutions were sought in techniques used in human interactions and everyday sharing of resources, such as television usage. These solutions have been applied to computing systems, but they still remain versions of common human activities. Some computer techniques have been named after their everyday counterparts and studying the human based concepts can help to understand their computer counterparts.

Contention for resources

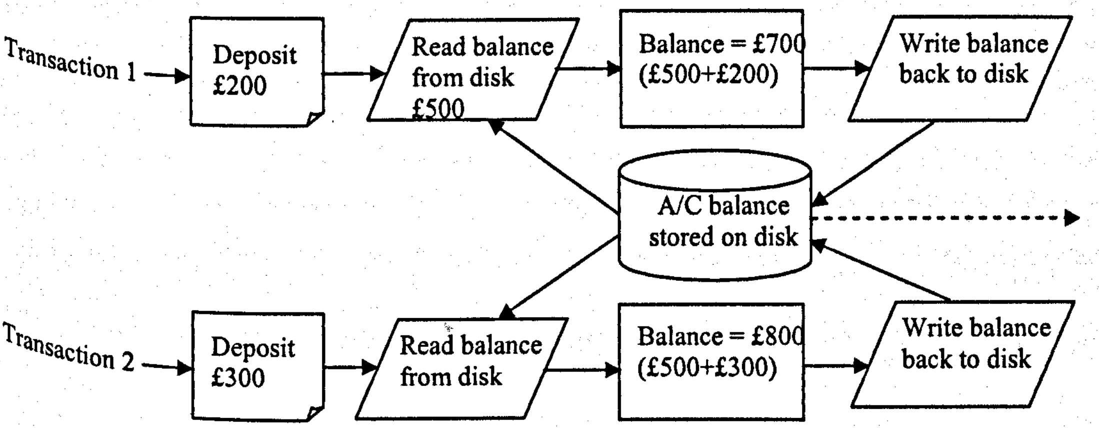
In an online banking system there will typically be a large database used to store all the information of account holders. One way to use such a database is to have it supported by a single computer with many workstations. Bank staff would enter customer enquiries at a workstation in response to phone calls. Examples of enquiries might be: 'What is the balance of current account number 51420430?' and 'What were the last seven transactions against account number 43261191?' Such enquiries only require 'read access' to the database. In this situation, programs that make the queries are called **readers** (of the database) as they read but do not write to the database in order to answer the query. The important property of a reader is that it makes no changes to the information it reads. This is important as it guarantees that the data remains consistent, i.e., it is the same at the beginning of a read query and after the query. As they make no changes to the data, readers can overlap their accesses to a database. This is termed **concurrency** – where two or more activities can overlap in time. From the perspective of the reader program it is as though each has its own copy of the database which it can read at will.

This is the general situation: if only readers access a resource, then each of those readers can behave as if they have a private copy of the resource.

In contrast, a write action or **writer** changes the data. An example of a query made by a writer is 'Set the balance of account number 51420430 to £1,000,000'. When a writer accesses a database, the database changes. Consequently, two states of the database can be identified when write actions or transactions occur in databases, i.e., the state *before* the write and the state *after* the write. Database management is complicated by writers, simply because they change the database. More generally, resource management is complicated by writers, simply because they change the resource.

Consider what happens when two write actions occur **concurrently**. By concurrently we mean transactions that are all somewhere between their start and finish points at the same time.

In an ordinary file system if two users are updating a file at the same time, the **read** and **write** commands will be carried out in the order received. In this example of a banking system, the account initially contains £500, and the transactions are to deposit £200 and £300, respectively.



The final balance should have been £1000 but as the transactions happened concurrently the final balance written back is £800.

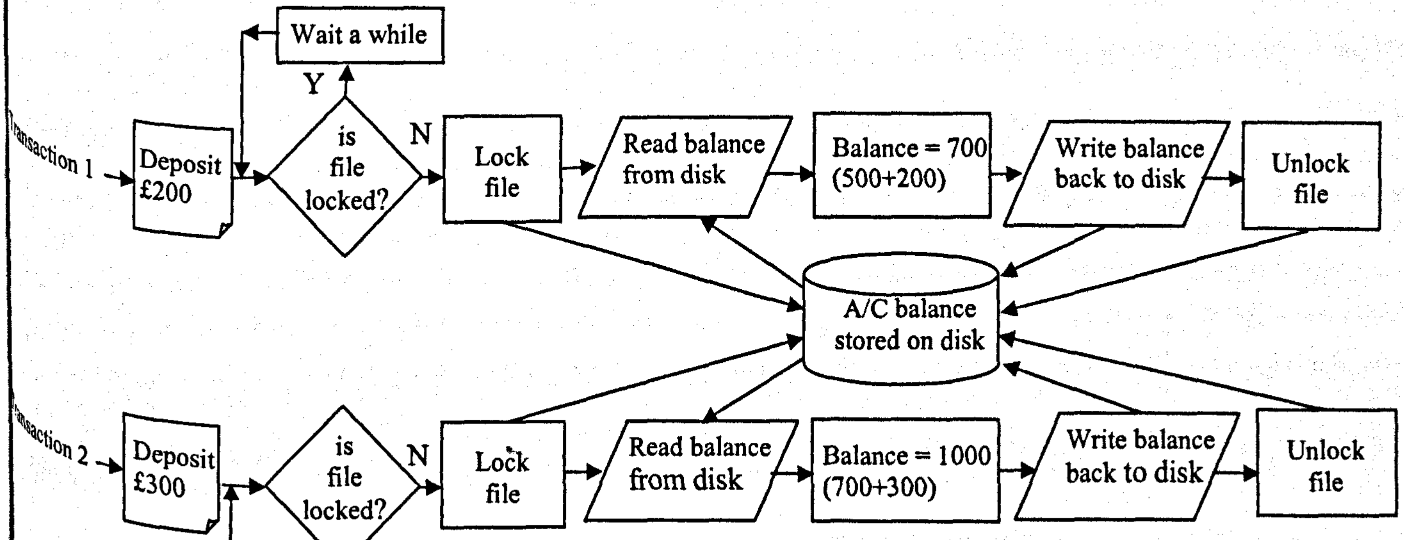
Figure 3, illustrating the problems when a resource is shared and the transactions are interleaved

As figure 3 illustrates *two transactions can have an undesired outcome when read and write actions are mixed together in this way.* If transaction 2 had been a little bit slower, the final balance written back to disk would have been £700. *In either case*, because the two updates are **interleaved** (i.e. the actions of one transaction are intermingled with the other and neither is completely finished before another begins), the *final result is wrong*. What is needed is a way to ensure that one transaction accesses the information and completes before another begins, and they are not interleaved as above.

This problem is another form of the destructive interference: two processes working with the same shared resource have the effect of compromising the correct state of the shared resource, even though each process is correct in its own manipulation of the resource. The problem arises because the processes make assumptions about the state of the resource – they both assume that the balance starts at £100 – an assumption invalidated by the actions of the other process. The destructive interference comes from the fact that each process is both a reader and a writer but that the reading and writing of one process are separated by the writing of the other.

The solution to this particular case of destructive interference is to allow the processes to assume something about the state of a shared resource, and to ensure that the process does its work in big enough chunks, uninterrupted by another process, so that those assumptions are valid throughout the operation. In the previous example, we would ensure reading and writing by one process were not interleaved with the reading and writing in the other.

Consider how this solution might work in terms of solving the interleaving problem. The diagram below illustrates how **file locking** is used to control access to a shared resource.



A/C balance is now correct. A transaction cannot access the file until any other concurrent transaction has unlocked it.

Figure 4, illustrating how locks can prevent the problems of interleaving

As figure 4 illustrates, locks can prevent the problems of interleaving. When we ensure that concurrent processes do not result in destructive interference we make them **serializable.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

In general resource management, the solution is similar to this example. Processes that use a resource should be able to complete all their work before a similar process begins. In effect, some operations on resources must either be allowed to finish or not start at all.

Atomicity

Although a computer executes programs at the instruction level, larger operations are made up of a group or sequence of instructions. If a process accesses shared resources, then any assumptions that the process makes about the resource state need to be identified. Any larger operation that makes these assumptions needs to be constructed so that its constituent instructions are made inseparable.

For example, imagine two processes requiring the same resource, such as a printer. If they both take it in turns to print their documents the result will be that printout will contain lines from one document and lines from another all intermingled. This would mean that the document produced represented neither a printout from the first process or the second.

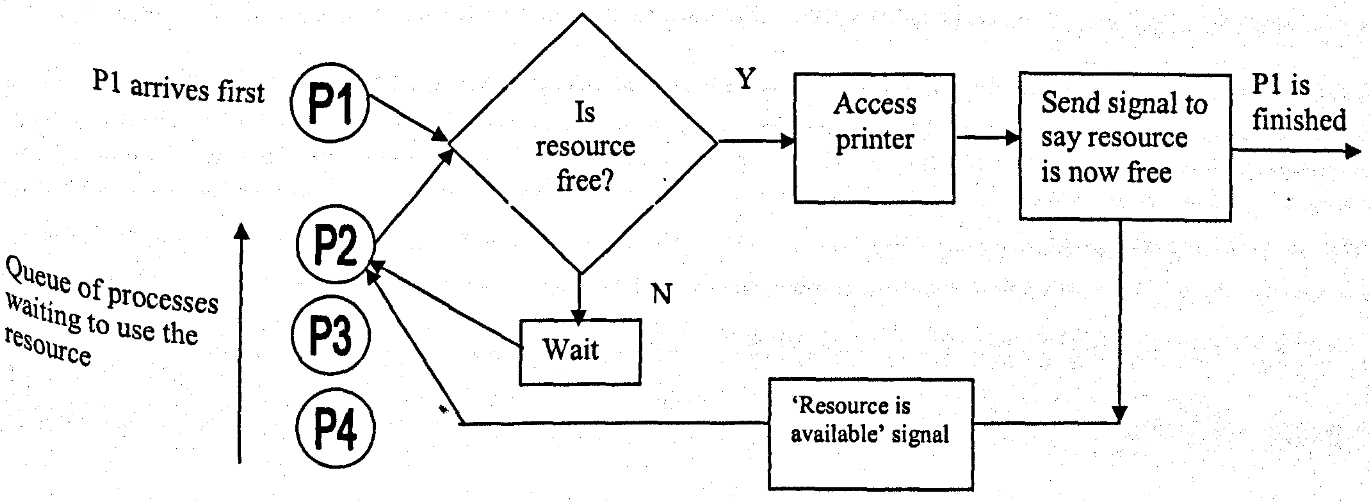


Figure 5, Illustrating resource contention

Therefore it is better either for the first process to complete the printing job and make other processes wait, than to start using the resource and not finish with it. Figure 5 illustrates how this might work in practice, with the first process to arrive being given access to the resource, while the following processes wait in a queue for access until the first process has finished with it. Either something happens in its entirety, or it doesn't happen at all. This concept is called **atomicity.** An action that must either complete or not start is called an **atomic action.** The word *atomic* means something that is whole and cannot be divided. In the case of the types of actions we are discussing here, it refers to this all-or-nothing property.

Respecting atomicity

Knowing that an action is atomic is all very well, but respecting the atomicity of the action is the responsibility of processes also in the system. So how do they know that an operation currently being executed by another process is atomic and, hence, is not to be interrupted?

One way that this is done is to protect the resource from access with a **lock** while an atomic action is accessing it. Lock is an everyday name – imagine a process locking a resource away when it wants to use it without being interrupted.

Locks on resources are administered by operating systems (or occasionally hardware), and locking is requested by a process wanting to execute an action atomically. A process requiring access to a resource that is locked must wait just like a train requiring a single length of track must wait if there is a train already using it. Interestingly, the way in which real trains on a single track solved the problem was to have a single key that locked and unlocked the signals guarding the track. Once you had the key you could set the signal to allow you to pass and you kept the key until you had cleared the track, when you would release the key for other users.

For example, suppose there is a laboratory that contains some special equipment that several researchers use from time to time to conduct experiments. If the equipment is free, the lab manager unlocks the lab door. As soon as a researcher wants the equipment, she gets the key and locks the lab while doing the experiment. This ensures that the experiment will complete even if it takes some time and the researcher leaves for a few minutes to get a cup of coffee, so long as the researcher ensures that the door to the lab is locked. When the experiment is completed, the researcher unlocks the door and returns the key to the lab manager so anyone else waiting for the lab can get the key and do their own experiment.

From the point of view of an operating system, all it needs to know for the management of a resource is its lock status, the setting of which is the responsibility of the process acquiring that resource. A process will notify the operating system before attempting to access that resource by executing a **wait** command, the parameter of which names the resource (e.g., **wait(track)** in the example of the train). By executing the **wait** command, a process is saying to the operating system that it's trying to access the identified resource, but is willing to *wait* if the resource is already locked by some other process. On a **wait** command, the operating system checks the lock status for the resource:

- If it is unlocked then the process is allowed to access it and the resource is locked to prevent other processes accessing it;
- If it is locked the process must wait until the resource becomes free. It is put in a queue of processes waiting to access that resource. The queue will record the order in which the process(es) attempted to access the resource and then give access in that order to the process(es) when the resource becomes free.

Telling the operating system that a resource has been released from an atomic action is the role of the **signal** operation, e.g., **signal(track)** when the track becomes free. A process executing a **signal** operation has finished using the resource. The operating system will record that the resource is available, and one of the processes waiting to access it (if any) will be activated.

Implementing locks using semaphores

Locks can be implemented using **semaphores**. A semaphore is another everyday concept and they are used as signals, rather like the train example where they are used to signal to train drivers if a single piece of train track is available and safe to use. This is precisely how they are used in operating systems: they signal whether a resource is in use or not and prevent other processes from using it while it is in use. The information that is required to implement a lock is:

- Identify the resource to which the lock refers;
- Record whether the resource is in use or not;
- Record which processes, if any, are waiting for the resource to become available.

A semaphore in an operating system is usually just a variable, the name of which can be chosen to identify the resource it refers to. Although other choices are possible, the simplest case is when a semaphore is a variable which can hold one of two values, typically **1** and **0**, (**1** if the resource is available, and **0** if the resource is not available). Such a semaphore is called a **binary semaphore**. Associated with this variable, there will also be a queue to record waiting processes.

Review Question 2

What will the initial value of a binary semaphore be?

Implementing *wait* and *signal*

The following is an example of code that is used to implement semaphores. For a process that is **waiting to gain access** to a resource, signalled by a binary semaphore, the operating system will perform the algorithm in the following figure.

Pseudo Code Example

```
If semaphore set to 1
then
     set semaphore to 0
     give resource to
     requestor
else
     suspend process
```

Meaning of code

If the value of the variable semaphore is **1** then this means that the process can use the resource. It then sets semaphore to **0** so that no other process can use it.

If the value of semaphore is not **1** then it means that the resource is not available and makes the process wait. What is not clear from this example of code is that the suspended process is put into a queue to await the resource being made available.

Figure 5, explaining the code in a wait semaphore

For a process that has been **given access to a resource**, signalled by a binary semaphore, the operating system will perform the following algorithm.

Pseudo Code Example

```
If queue(resource) is not empty
then
     wake first process in queue(resource)
     set semaphore to 0
     give resource to requestor
else
     set semaphore to 1
```

Meaning of code

The first statement checks to see if the queue for a particular resource (say a printer) is empty. It acts like a function that returns either a value of empty or not empty. If the queue is not empty it then **wakes** the first process in that queue in readiness to access to the resource. The semaphore for this resource is now set to **1**, which means that this process has access to the resource.

Figure 6, explaining the code in a signal semaphore

Summary

In resource management an operating system must manage the multiple requests for a popular resource, just like in our homes the request to watch a particular programme on one television must be managed.

If a resource is not properly managed then the outcome of a process (or transaction) can be compromised as its constituent instructions may have been interleaved with those of another process and subsequently the result is incorrect, even though the task itself had been carried out correctly.

Operations are called atomic actions when they must either complete or not start at all. Similarly atomicity requires a task to complete or not to start at all. Atomicity is respected by implementing locks. These ensure that when a resource is in use no other process can access it.

Locks are controlled by the use of semaphores, which indicate whether a resource is available for use. The simplest of these is a binary semaphore that controls a single resource. It uses a 1 to indicate if the resource is available for use and 0 to indicate that the resource is in use and the requesting process must wait.

Resource management is a very important job performed by the operating system. It manages multiple processes in all types of computer systems, both singles user (the familiar PC) and multiple user systems (one large computer facilitating many users).

Dealing with multiple processes: resource management

As a child I always wanted my own television set. Today, I suspect that the majority of children have their own. Many households therefore have 2, 3 or even more televisions. Conversely you don't see many households with more than one oven. So what is it about televisions that makes people want one each?

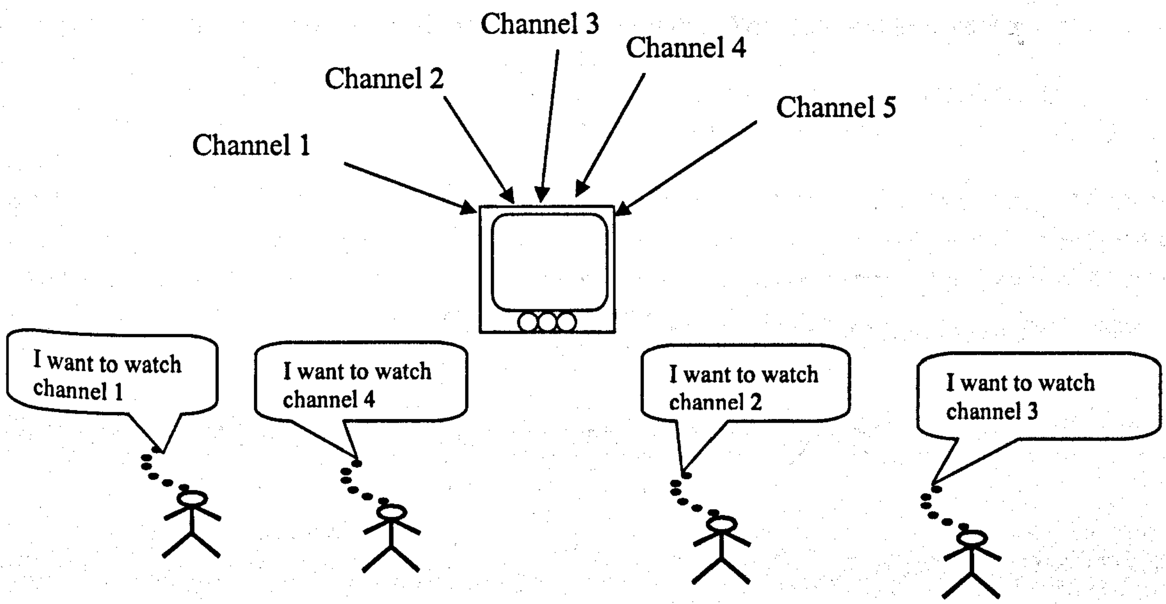


Figure 1, several people wanting to watch different channels on a television

A single television can only show one channel's programme at a time. In a single television home, with something good showing - a blockbuster film perhaps - everyone will be happy to watch it. However, as the diagram illustrates a television set may receive several channels at once, but it can only show one at a time, and if several people want to watch different channels they can't do so on the same television set. If the single television home is also a single video home as well, it maybe possible, if the potential viewers are flexible, to negotiate an agreement in which one watches in real-time and the other records. That's not always a perfect solution however as perhaps both wanted to record a programme!

Review Question 1

Why might a household want to have several television sets but not several ovens?

One television is required if both parties want to watch the same program. One television and one video are required if one party can be convinced to record a programme while the other watches. Two televisions will be required if both parties want to watch what they want immediately. Two videos will be required if both want to record for later. It's a problem of resources and resource management.

It's the same with computers: two processes that want to use the same resource may be able to without problem. Either their uses will be compatible and they can make do with one copy, or users will 'negotiate' who gets to use the single copy first, and in which way.

This is similar to the problem that a teacher faces when they have only one small chalkboard on which to write. As figure 2 illustrates, the teacher may fill the board with all the relevant information but if a students asks for some further explanation, say in the form of a worked example, the teacher has to decide whether to ignore the student and keep what is on the board, or wipe what is on the board to meet the request of the student.

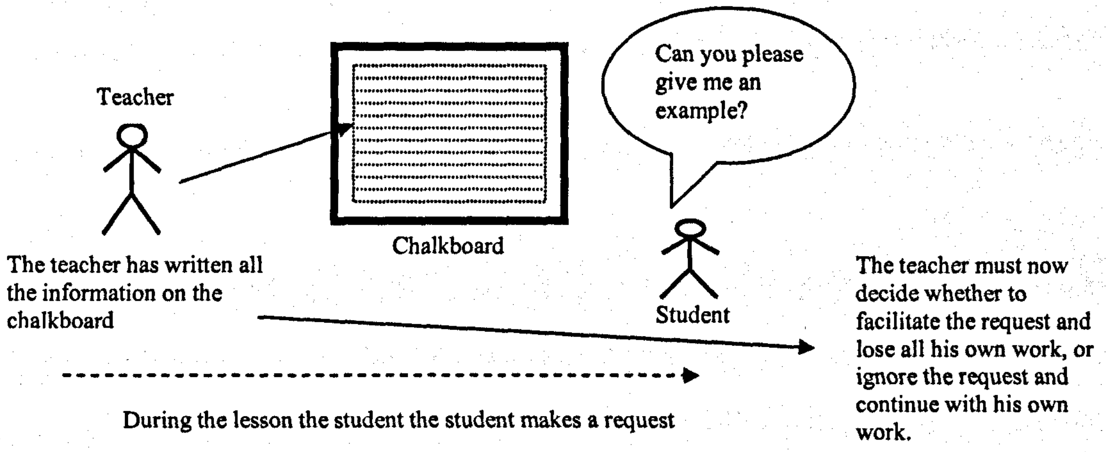


Figure 2, illustrating the competing recourses in a lesson

Likewise, the operating system has to negotiate between competing requests just as the teacher has. For example there may be an incoming email that needs some memory in order for it to be read, while at the same time there is a request from the word processor for some memory also. If an email is already in memory then allocating memory to the word processor will result in the email being lost – rather like the teaching wiping his chalkboard. If the negotiation isn't done correctly, and the OS first assigns space to the email message then the same space to the new document, the email message will effectively be lost when it is overwritten in memory. This is called **destructive interference.**

In computer operating systems processes need to negotiate for the use of resources such as space in memory, or use of a printer. Today, understanding of the techniques for negotiation is almost complete (though they still cause problems when put into practice!). Originally this was anything but the case: the operation of computing systems involving multiple processes was rather a hit and miss affair. To solve the problems, solutions were sought in techniques used in human interactions and everyday sharing of resources, such as television usage. These solutions have been applied to computing systems, but they still remain versions of common human activities. Some computer techniques have been named after their everyday counterparts and studying the human based concepts can help to understand their computer counterparts.

Contention for resources

In an online banking system there will typically be a large database used to store all the information of account holders. One way to use such a database is to have it supported by a single computer with many workstations. Bank staff would enter customer enquiries at a workstation in response to phone calls. Examples of enquiries might be: 'What is the balance of current account number 51420430?' and 'What were the last seven transactions against account number 43261191?' Such enquiries only require 'read access' to the database. In this situation, programs that make the queries are called **readers** (of the database) as they read but do not write to the database in order to answer the query.

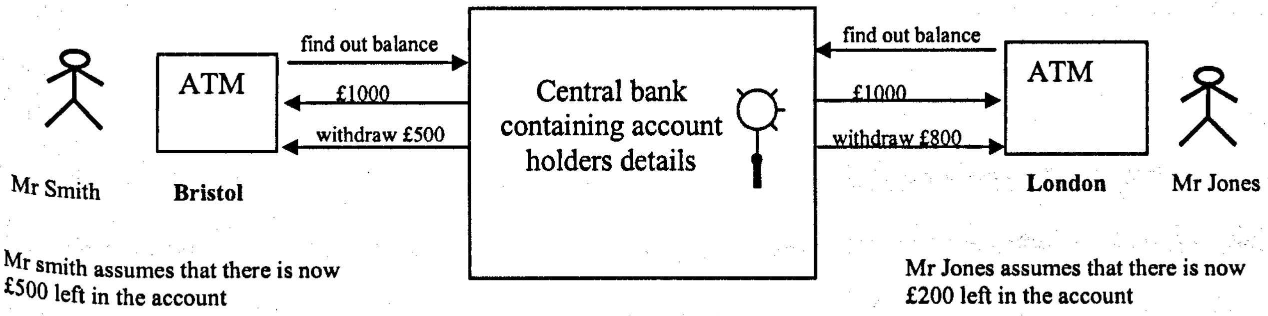
The important property of a reader is that it makes no changes to the information it reads. This is important as it guarantees that the data remains consistent, i.e., it is the same at the beginning of a read query and after the query. As they make no changes to the data, readers can overlap their accesses to a database. This is termed **concurrency** – where two or more activities can overlap in time. From the perspective of the reader it is as though each has its own copy of the database which it can read at will.

This is the general situation: if only readers access a resource, then each of those readers can behave as if they have a private copy of the resource.

In contrast, a write action or **writer** changes the data. An example of a query made by a writer is 'Set the balance of account number 51420430 to £1,000,000'. When a writer accesses a database, the database changes. Consequently, two states of the database can be identified when write actions occur in databases, i.e., the state *before* the write and the state *after* the write. Database management is complicated by writers, simply because they change the database. More generally, resource management is complicated by writers, simply because they change the resource.

Consider what happens when two write actions occur **concurrently**. By concurrently we mean transactions that are all somewhere between their start and finish points at the same time.

There are two partners in a company both of who have access to a company bank account. Mr Smith is visiting a client in Bristol while Mr Jones is visiting a client in London. Both of them go to an automatic teller machine to withdraw money concurrently, i.e., at the same time. By concurrently we mean transactions that are all somewhere between their start and finish points.



Mr smith assumes that there is now £500 left in the account

Mr Jones assumes that there is now £200 left in the account

Neither assumption is right. As they were both processing information concurrently the transactions were intermingled. The balance is in fact £300 overdrawn.

Figure 3, illustrating the problems when two people access the same information at the same time

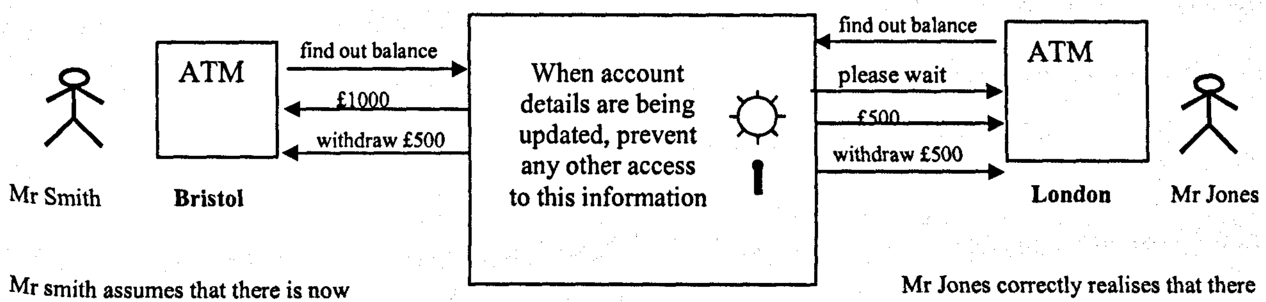
The problem arises because the two actions are **interleaved,** (i.e. the actions of one transaction are intermingled with another and neither is completely finished before another begins), the final result is not what either partner expected. As figure 3 illustrates *two transactions can have an undesired outcome when two transactions are mixed together in this way*. What is needed is a way to ensure that one transaction accesses the information and completes before another begins, and they are not interleaved as above.

This problem is another form of the destructive interference: two processes working with the same shared resource have the effect of compromising the correct state of the shared resource, even though each process is correct in its own manipulation of the resource. The problem arises because the processes make assumptions about the state of the resource – they both assume that the balance starts at £1000 – an assumption invalidated by the actions of the other process.

The destructive interference comes from the fact that each process is both a reader and a writer but that the reading and writing of one process are separated by the writing of the other.

The solution to this particular case of destructive interference is to allow the processes to assume something about the state of a shared resource, and to ensure that the process does its work in big enough chunks, uninterrupted by another process, so that those assumptions are valid throughout the operation. In the above example, we would ensure reading and writing by one process were not interleaved with the reading and writing in the other.

Consider how this solution might work in terms of solving the interleaving problem. The following diagram illustrates how **file locking** is used control access to share resources.


Central bank containing account holders details

Mr smith assumes that there is now £500 left in the account

Mr Jones correctly realises that there is only £500 left in the account, so he can only withdraw £500

In this situation both parties now have the correct information on the account as Mr Jones transaction was delayed as he was unable to access the information while Mr Smith withdrew his money.

Figure 4, illustrating how locks can prevent the problems of interleaving

Figure 4 illustrates how locking can overcome the problems of interleaving by denying access to any other transaction until the current transaction is complete. When we ensure that concurrent processes do not result in destructive interference we make them **serializable.** Techniques to achieve serializability are called **concurrency control algorithms.** They are widely used in data base systems and file servers.

In general resource management, the solution is similar to this example. Processes which use a resource should be able to complete all their work before a similar process begins. In effect, some operations on resources must either be allowed to finish or not start at all.

Atomicity

Although a computer executes programs at the instruction level, larger operations are made up of a group or sequence of instructions. If a process accesses shared resources, then any assumptions that the process makes about the resource state need to be identified. Any larger operation that makes these assumptions needs to be constructed so that its constituent instructions are made inseparable.

For example, imagine two trains moving down two different tracks. At one point, the two tracks merge into a section of single track. It is safe for a train to pass over this single section of track provided no other train tries to enter the single section until the first train has passed completely over it. If a train is going to pass over a single section of track, it has to do so completely to free the track for any other train. If the train is likely to be stopped on the single section, or decouple a carriage on the single section, then that section is put out of action for some time to come.

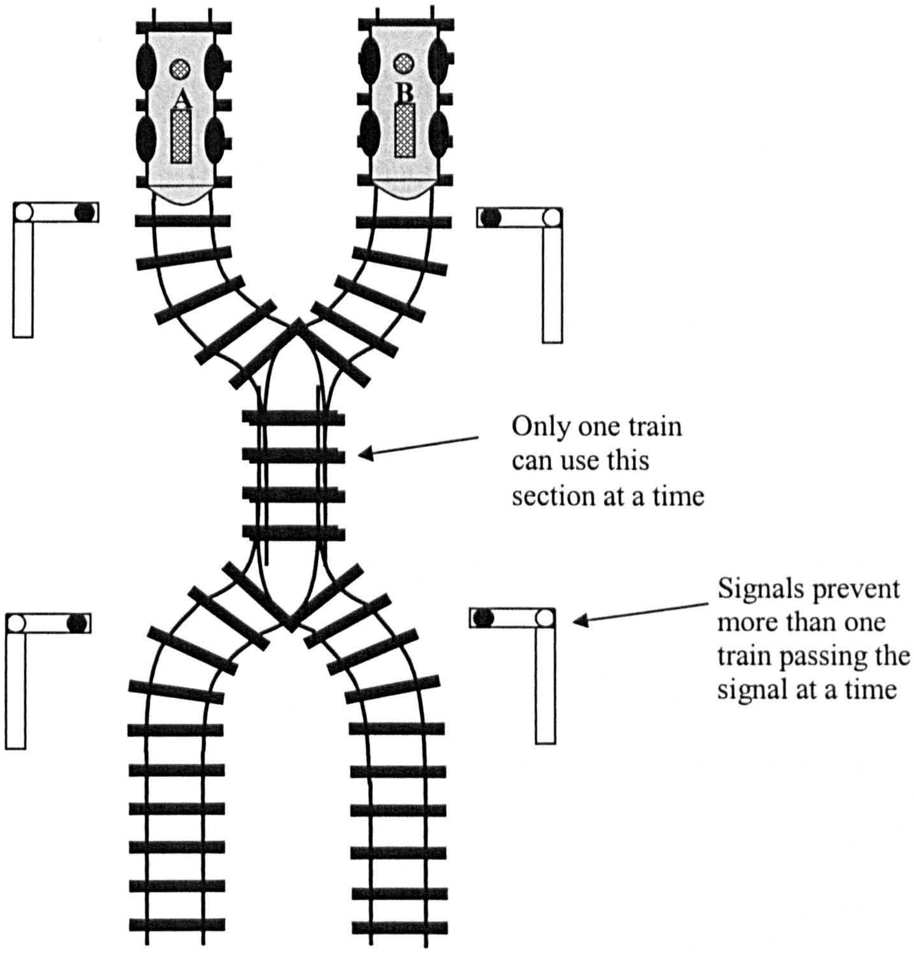


Figure 5, Illustrating resource contention in railway tracks

As figure 5 illustrates the single piece of track can only be used by one train at a time. Therefore it is better either for the train to pass completely over the single section or not to enter it at all. Either something happens in its entirety, or it doesn't happen at all. This concept is called **atomicity**. The action that must either complete or not start is called an **atomic action.** The word *atomic* means something that is whole and cannot be divided. In the case of the types of actions we are discussing here, it refers to this all-or-nothing property.

Respecting atomicity

Knowing that an action is atomic is all very well, but respecting the atomicity of the action is the responsibility of processes also in the system.

So how do they know that an operation currently being executed by another process is atomic and, hence, is not to be interrupted?

The usual way that this is done is to protect the resource from access with a **lock** while an atomic action is accessing it. Lock is an everyday name – imagine a process locking a resource away when it wants to use it without being interrupted.

Locks on resources are administered by operating systems (or occasionally hardware) and locking is requested by a process wanting to execute an action atomically. A process requiring access to a resource that is locked must wait just like a train requiring a single length of track must wait if there is a train already using it. Interestingly, the way in which real trains on a single track solved the problem was to have a single key that locked and unlocked the signals guarding the track. Once you had the key you could set the signal to allow you to pass and you kept the key until you had cleared the track, when you would release the key for other users.

For example, suppose there is a laboratory that contains some special equipment that several researchers use from time to time to conduct experiments. If the equipment is free, the lab manager unlocks the lab door. As soon as a researcher wants the equipment, she gets the key and locks the lab while doing the experiment. This ensures that the experiment will complete even if it takes some time and the researcher leaves for a few minutes to get a cup of coffee, so long as the researcher ensures that the door to the lab is locked. When the experiment is completed, the researcher unlocks the door and returns the key to the lab manager so anyone else waiting for the lab can get the key and do their own experiment.

From the point of view of an operating system, all it needs to know for the management of a resource is its lock status, the setting of which is the responsibility of the process acquiring that resource. A process will notify the operating system before attempting to access that resource by executing a **wait** command, the parameter of which names the resource (e.g., **wait(track)** in the example of the train). By executing the **wait** command, a process is saying to the operating system that it's trying to access the identified resource, but is willing to *wait* if the resource is already locked by some other process. On a **wait** command, the operating system checks the lock status for the resource:

- If it is unlocked then the process is allowed to access it and the resource is locked to prevent other processes accessing it;
- If it is locked the process must wait until the resource becomes free. It is put in a queue of processes waiting to access that resource. The queue records the order in which the process(es) tried to access the resource and access will be given to the first process in the queue when the resource becomes available.

Telling the operating system that a resource has been released from an atomic action is the role of the **signal** operation, e.g., **signal(track)** when the track becomes free. A process executing a **signal** operation has finished using the resource. The operating system will record that the resource is available, and one of the processes waiting to access it (if any) will be activated.

Implementing locks using semaphores

Locks can be implemented using **semaphores**. A semaphore is another everyday concept and they are used as signals, rather like the train example where they are used to signal to train drivers if a single piece of train track is available and safe to use. This is precisely how they are used in operating systems: they signal whether a resource is in use or not and prevent other processes from using it while it is in use. The information that is required to implement a lock is:

- Identify the resource to which the lock refers;
- Record whether the resource is in use or not;
- Record which processes, if any, are waiting for the resource to become available.

A semaphore in an operating system is usually just a variable, the name of which can be chosen to identify the resource it refers to. Although other choices are possible, the simplest case is when a semaphore is a variable which can hold one of two values, typically **1** and **0**, (**1** if the resource is available, and **0** if the resource is not available). Such a semaphore is called a **binary semaphore**. Associated with this variable, there will also be a queue to record waiting processes.

Review Question 2

What will the initial value of a binary semaphore be?

Implementing *wait* and *signal*

The following is an example of code that is used to implement semaphores. For a process that is **waiting to gain access to a resource,** signalled by a binary semaphore, the operating system will perform the algorithm in the following figure.

Pseudo Code Example

```
If semaphore set to 1
then
    set semaphore to 0
    give resource to requestor
else
    suspend process
```

Meaning of code

If the value of the variable semaphore is **1** then this means that the process can use the resource. It then sets semaphore to **0** so that no other process can use it.

If the value of semaphore is not **1** then it means that the resource is not available and makes the process wait. What is not clear from this example of code is that the suspended process is put into a queue to await the resource being made available.

Figure 5, explaining the in a wait semaphore

For a process that has been given access to a resource, signalled by a binary semaphore, the operating system will perform the following algorithm.

Pseudo Code Example

```
If queue(resource) is not empty
then
    wake first process in queue(resource)
    set semaphore to 0
    give resource to requestor
else
    set semaphore to 1
```

Meaning of code

The first statement checks to see if the queue for a particular resource (say a printer) is empty. It acts like a function that returns either a value of empty or not empty. If the queue is not empty it then **wakes** the first process in that queue in readiness to access to the resource. The semaphore for this resource is now set to **1**, which means that this process has access to the resource.

Figure 6, explaining the code in a signal semaphore

Summary

In resource management an operating system must manage the multiple requests for a popular resource, just like in our homes the request to watch a particular programme on one television must be managed.

If a resource is not properly managed then the outcome of a process (or transaction) can be compromised as its constituent instructions may have been interleaved with those of another process and subsequently the result is incorrect, even though the task itself had been carried out correctly.

Operations are called atomic actions when they must either complete or not start at all. Similarly atomicity requires a task to complete or not to start at all. Atomicity is respected by implementing locks. These ensure that when a resource is in use no other process can access it.

Locks are controlled by the use of semaphores. These are signals, similar in idea to those used in railway lines, which indicate whether a resource (or section of railway track) is available for use.

The simplest of these is a binary semaphore that controls a single resource. It uses a 1 to indicate if the resource is available for use and 0 to indicate that the resource is in use and the requesting process must wait.

Resource management is a very important job performed by the operating system. It manages multiple processes in all types of computer systems, both singles user (the familiar PC) and multiple user systems (one large computer facilitating many users).

Appendix J: Post-Tests for Study 2

Concurrency Post-test

Please read the following

Please do NOT turn over the page until instructed to do so — this is so everyone can start together. The purpose of the test is to assess if the learning materials you have read are appropriate for helping you to learn this material. **You are not being testing**, the materials are, so please do not worry if there are answers you cannot complete.

There are 3 tests in total. The first will take 20 minutes to complete, the second will take 35 minutes and the third will take 2 minutes to complete. You will be given the instructions for each test before you begin.

Please feel free to write any comment you wish anywhere in the page that you feel is appropriate. As we are interested in what works for **YOU** the student we need all the feedback we can get, so all comments are welcome – even if you feel they are negative.

Recall Post-test

Please do not turn over the page until instructed to do so. You will have **20 minutes** to complete this part of the test. If you do not get everything finished within the time limit and you have more to say, please note this on the sheet.

Recall Post-test

Please write down all that you can remember from the material you have just read. Try aiming at explaining this for beginners. As this exercise is time limited, you might try starting by identifying the main concepts and the key ideas within these concepts. However, please feel free to tackle this task in any way you feel is appropriate. You are welcome to use any form of presentation. For example, you might want to represent this by using key phrases, key words, sentences, paragraphs, diagrams, or tables. These are only some ideas to get you started, please use whatever method suits you best.

Recall Post-test

Transfer Post Test

Please do not turn over the page until instructed to do so. You will have **35 minutes** to complete this part of the test. If you do not get everything finished within the time limit and you have more to say, please note this on the sheet.

Transfer Post Test

1. Identify one way in which interleaved access might be possible in a television viewing situation. What is the mechanism that would enable this to work?

Please explain how it would work.

What are the important parts of the solution that make it work?

2. Imagine that you have just used your cash card in a cash dispenser to withdraw £50 from your current account. At precisely the same time a bank clerk is entering a transaction to record a deposit to your account of £50 which has just arrived in the post. As the transactions are occurring simultaneously, the balance read at the beginning of both transactions will be the same, say £100. What happens if *your* transaction takes £100 as the balance, subtracts £50 and writes the new balance back to the account at the same time as the bank clerk's transaction takes the balance of £100, adds £50 to it and writes the new balance back?

   How could you cheat and end up with more money than you should?

   If semaphores were used to control access to the account, would it be an atomic operation?

   If this were an atomic operation would you be able to cheat in the same way?

   Why or why not?

3. Give an example of an everyday operation that should be atomic and draw a diagram to illustrate what happens. You do not need to use the same symbols that were used in the text. If you can't draw a diagram explain your answer in words. (You can use an example from the materials you have just read if you wish.)

The primary school eraser problem

At an old-fashioned village school in the south of England they have an unusual rule for the children. The pupils must all work in pencil and they can only erase their work using the teacher's special eraser. When a pupil makes a mistake he or she must go to the teacher's desk and request the eraser. If no one else is using the eraser then the pupil is given it to go back to his or her desk and erase the mistake. When finished with the eraser the pupil returns it to the teacher. If a pupil needs to borrow the eraser from the teacher and it is already in use, the pupil must return to his or her desk and wait. When the eraser becomes available again then the teacher calls the waiting pupil and gives him or her the eraser. If several pupils need to use the eraser the teacher records the names of the pupils in a queue and each pupil receives the eraser in turn.

The following pseudocode models the actions of the rule controlling access to the eraser.

```
Eraser_available
     If eraser_free true
     then
          set eraser_free to false
          give pupil_eraser
     else
          tell pupil to wait in queue(eraser)
```

4. Write a piece of pseudocode that models the action of teacher controlling the queue for the eraser. If you cannot manage to write pseudocode describe your answer in words.

Explain in your own words how this actually works.

5. What is the restricted resource? Explain your answer briefly.

What role does the teacher play in the concurrency issue?

6. What would eventually happen if a pupil forgets to return the eraser?

7. Can you describe another everyday situation where concurrency is an issue?

Why is concurrency an issue in this situation?

8. In your chosen example (in the previous question), how would you solve this problem in practice? Explain what the mechanism would be.

9. Explain what the possible conflict is in your chosen example, and what would happen if nothing were done to control the situation.

Verbatim Recognition Post-test

Please do not turn over the page until instructed to do so. You will have **2 minutes** to complete this part of the test.

Verbatim Post-test

Please read the following pair of sentences and put a tick against the one that you think appeared exactly (verbatim) in the materials you have just read.

1

A single television can only show one channel's programme at a time. ☐

Only one channel can be shown on a television at a time. ☐

2

It is the role of the operating system to negotiate on the use of resources for processes. ☐

In computer operating systems processes need to negotiate for the use of resources. ☐

3

If a concurrent process produces the same result whether the updates occur at the same time, or one after the other, we say that it is serializable. ☐

A concurrent process is serializable when it produces the same result regardless of whether the updates occur one after the other or at the same time. ☐

4

Although a computer executes programs at the instruction level, larger operations are made up of a group or sequence of instructions. ☐

A computer generally executes programs instruction by instruction, however a sequence of instructions will usually make up a larger operation. ☐

5

An atomic action is one that must either complete or not start at all. ☐

The action that must either complete or not start is called an atomic action. ☐

6

Telling the operating system that a resource has been released from an atomic action is the role of the signal operation ☐

It is the role of the signal operation to tell the operating system that a resource has been released from an atomic action. ☐

7

The name of a semaphore is chosen to identify the resource to which it refers and is usually just a variable. ☐

A semaphore in an operating system is usually just a variable, the name of which can be chosen to identify the resource it refers to. ☐

8

A binary semaphore can only manage a lock on a single resource. ☐

A lock on a single resource is managed by a binary semaphore. ☐

Name________________________________

PI____________________________

Date_______________________

Group_____________

Institution____________________________

Introspective Report on Study Approach and Recall Approach

In this section we are particularly interested in how you went about studying the material and also how you remember the information in the tests. If you can write down as much as you can about these activities we would really appreciate it.

We shall give you back the notes that you have made and the original materials so you can use these to help you remember how you went about studying the material and later how you remembered it. You will be given a red pen to complete this section with and you can also use this pen to write anything else you feel is appropriate on the original materials and your notes.

In particular if you have any comments on the diagrams and how they helped or impeded your learning of the concepts, please note this down on the materials.

All information will be treated with strict confidence.

There is no time limit for this section.

Introspective Report on studying the material

In this section we would like you to record how you went about studying the materials. What types of things did you do? What sorts of things where you thinking? How were you storing this information in your head?

We are really interested in the process you went through in this study activity and anything that you can write here that tells us how you went about this task would be extremely useful.

Introspective Report on how they recalled the information for the post-tests

In this section we would like you to record how you went about remembering the information in the materials during the post-tests. What types of things did you do? What sorts of things where you thinking? How did you remember this information?

We are really interested in the process you went through in this recall activity for the post-tests and anything that you can write here that tells us how you went about this task would be extremely useful.

How many hours on average do you spend studying M206 each day?

Name________________________________

PI______________________________

Date_________________________

Group______________

Institution______________________________

Appendix K: Scoring Sheet for the Student Questionnaire

Scoring the Student Questionnaire

Field name	Label	How to score
Group		A = Abstract C = Concrete Depends on which set of materials they have been given
Compuser	Computer Use – level and experience of computer use	Q2: Add up the value of all the numbers that have been ticked except for the subparts 5,6,7,8
Compdev	Computer Development – how much they use the computer for development	Q2, subparts 5,6,7,8: add up the value of these subparts that all refer to using the computer for development. Max=20
Topickno	Prior Knowledge	For each course the levels are scored from left to right as follows:- ONC/OND GNVQ Level 2 =1 HNC/HND GNVQ Level 3 = 2 Undergraduate course =3 Postgraduate course = 4 Short training course = 5 This is knowledge of the topics used in the materials.
Age		Wide groupings – as on questionnaire 1 = under 24 2 = 25-29 3 = 30-39 4 = 40-49 5 = 50-59 6 = 60-64 7 = over 65
Gender		M/F
Yrscomp	Years using a computer	Q2, 1 = under 1 2 = 1-5 3 = 6-10 4 = 11-15 5 = 15-20 6 = over20
Educ		Q10 – level of education 1 = No formal qualifications 2 = CSE RSA School Certificate 3 = O Level/GCSE (1-4 subjects) 4 = O Level/GCSE (5 or more subjects) 5 = Professional qualification : less than A Level standard 6 = A level (1 subject) 7 = A level (2 or more subjects) 8 = ONC/OND/NVQ Level 2 9 = Professional qualification: less than degree 10 = HNC/HND/NVQ level 3 11 = Teachers Certificate 12 = University Diploma 13 = University 1st Degree 15 = Postgraduate degree

		16 = Professional Qualification: degree or higher Other (*Please comment*)
Age2	Age in smaller groupings	Used to group in smaller bands to see if age was a factor 1 = under 29 2 = 30 - 39 3 = 40 - 49 4 = 50 - 59 (should probably be 50 and over)

Appendix L: Protocol Analysis

Encoding of Protocols

Study Practices

Protocol Code	Definition
AQ	Assessing the quality of the document
CS	Makes change in strategy
CP	Cued by presentation to attend to particular words, phrases etc
DAI	Uses diagrams to anchor information
DD	Draws diagrams
DIS	Discard irrelevant information
DU	Diagrams read for understanding
FD	Forgot diagram Memory loss on diagrams –
HI	Highlighting sections
IFS	Identifies flaw in strategy
IKP	Identify key learning points
IMS	Identifies own metastrategies
LC	Lost concentration
LI	Lost interest
MEM	Memorises – uses rote learning
MN	Makes notes
MMI	Makes mental image
MSC	Makes strategy change
OO	Obtain overview of the subject
RA	Reads through all of the document
RC	Reads through a chunk of the document
RCE	Relates to concrete experience or associates with other experience or knowledge
REF	Reflect
REW	Reword into own words – made own summary
RK	Review knowledge at different points for understanding
RN	Review own notes
RR	Re-reads
RU	Read for understanding, read carefully
SC	Scanning text
UND	Understands – uses deep learning

Recall Processes

Protocol Code	Definition
UTR	Using text to cue recall (visualised), i.e. bold, italics, keywords, headings
UDR	Uses diagrams to recall information (visualised)
NC	No cues readily available. Diagrams do not provide easy recall, i.e. easy associations with stored information. Forgot text even though digram was remembered.
US	Used the structure/sequence of information to cue recall
UKC	Uses Key Concepts to cue recall
RRCE	Recall: Uses concrete experience or association with other experience or knowledge to cue recall
UE	Used examples to prompt recall
RMEM	Recall: Use memorisation (rote learning) to remember. Remember notes to cue recall
RUND	Recall: Uses Understanding of topic to recall – uses deep learning

Appendix M: Scoring the Background Questionnaire

Scoring the Student Questionnaire

Field name	Label	How to score
Group		A = Abstract C = Concrete Depends on which set of materials they have been given
Compuser	Computer Use – level and experience of computer use	Q2: Add up the value of all the numbers that have been ticked except for the subparts 5,6,7,8
Compdev	Computer Development – how much they use the computer for development	Q2, subparts 5,6,7,8: add up the value of these subparts that all refer to using the computer for development. Max=20
Topickno	Prior Knowledge	For each of the 4 courses the levels are scored from left to right as follows:- ONC/OND GNVQ Level 2 =1 HNC/HND GNVQ Level 3 = 2 Undergraduate course =3 Postgraduate course = 4 Short training course = 5 This is knowledge of the topics used in the materials. Max score = 20
Age		Wide groupings – as on questionnaire 1 = under 24 2 = 25-29 3 = 30-39 4 = 40-49 5 = 50-59 6 = 60-64 7 = over 65
Gender		M/F
Yrscomp	Years using a computer	Q2, 1 = under 1 2 = 1-5 3 = 6-10 4 = 11-15 5 = 15-20 6 = over20

Educ		Q10 – level of education 1 = No formal qualifications 2 = CSE RSA School Certificate 3 = O Level/GCSE (1-4 subjects) 4 = O Level/GCSE (5 or more subjects) 5 = Professional qualification : less than A Level standard 6 = A level (1 subject) 7 = A level (2 or more subjects) 8 = ONC/OND/NVQ Level 2 9 = Professional qualification: less than degree 10 = HNC/HND/NVQ level 3 11 = Teachers Certificate 12 = University Diploma 13 = University 1st Degree 15 = Postgraduate degree 16 = Professional Qualification: degree or higher Other (*Please comment*)
Age2	Age in smaller groupings	Used to group in smaller bands to see if age was a factor 1 = under 29 2 = 30 - 39 3 = 40 - 49 4 = 50 - 59 (should probably be 50 and over)

Appendix N: Marking Scheme for Study 2

Marking scheme for study 2

Most of the concepts listed are terms that have been emboldened in the text. 1 mark is awarded for mentioning the concept and 2 marks for correctly explaining it. However, a few of the concepts are implied and required a deeper reading and understanding in order to be recalled and correctly explained. As such these implied concepts are awarded 1 for being mentioned and 3 marks for a correct explanation, with the exception of the first concept which was sufficiently explained in depth to warrant only 2 marks. The semaphores concept was also weighted with an extra two marks for reproduction, as this was a further demonstration of a level of explanation. A further 5 marks is available for any evidence of novel application of the concept (it is not anticipated that there will be many examples of this).

Recall post-test

No	Key concept	Explanation	Marks
1	Allocation of Resources (Implied concept but well explained - thus 2 marks)	Family members need to negotiate for viewing of TV – a limited resource – to avoid conflicts. **OR** A process needs to negotiate for computer resources – eg email and Word both requiring computer memory at the same time.	1 for mentioning concept 2 for explanation 5 for novel application
2	Readers	Has read only access to data and does not affect the state of the data or makes no changes to the information.	1 for mentioning concept 2 for explanation 5 for novel application
3	Writers	Has write access to the data and can change the state of the data.	1 for mentioning concept 2 for explanation 5 for novel application
4	Concurrency (Concurrently and concurrency are mentioned separately however they infer the same thing)	Is the ability to carry out more than one action at a time, i.e. two actions that overlap in time	1 for mentioning concept 2 for explanation 5 for novel application
5	Interleaving	The actions of one transaction are intermingled with the other and neither is completely finished before another begins. As such the result can be wrong or inconsistent.	1 for mentioning concept 2 for explanation 5 for novel application

6	Destructive Interference	Two processes working with the same shared resource have the effect of compromising the correct state of the shared resource, even though each process is correct in its own manipulation of the resource. E.g. if two processes were to access the same resource, overlapping in time, the final state of the resource could be compromised by interleaved read and write actions.	1 for mentioning concept 2 for explanation 5 for novel application
7	Negotiation	Rules for requesting and allocation of resources where these can be contended for.	1 for mentioning concept 3 for explanation 5 for novel application
8	Locking	This can prevent the problems of interleaving by preventing any other process accessing the resource while the current process is using it.	1 for mentioning concept 2 for explanation 5 for novel application
9	Data consistency	Data remains the same at the end of the "read" as at the beginning.	1 for mentioning concept 3 for explanation 5 for novel application
10	Serializable	This is a method of ensuring that concurrent processes do not result in destructive interference by having one action of a process completed in its entirety before an action of another process begins.	1 for mentioning concept 2 for explanation 5 for novel application
11	Concurrency Control Algorithms	These are techniques that are used to achieve serializability and prevent destructive interference	1 for mentioning concept 2 for explanation 5 for novel application
12	Semaphores	Semaphores signal whether a resource is in use or not and prevent other processes from using it while it is in use. E.g. they can be used to signal to train drivers if a single piece of train track is available and safe to use. Locks can be implemented using **semaphores**. A semaphore in an operating system is usually just a variable, the name of which can be chosen to identify the resource it refers to.	1 for mentioning concept 2 for explanation 5 for novel application

13	Binary Semaphores	A **Binary Semaphore** is a variable which can hold one of two values, typically **1** and **0**, (**1** if the resource is available, and **0** if the resource is not available). Associated with this variable will be a queue to record waiting processes. Reproduction of figure 5 in the text.	1 for mentioning concept 2 for explanation 2 for reproduction 5 for novel application
14	Atomicity	Either something happens in its entirety, or it doesn't happen at all.	1 for mentioning concept 2 for explanation 5 for novel application
15	Respecting Atomicity	An agreement between all of the processes to respect the rules for atomicity of any one of them.	1 for mentioning concept 3 for explanation 5 for novel application
16	Atomic Action	This is an action that must either complete or not start at all. The word *atomic* means something that is whole and cannot be divided. It refers to an all-or-nothing property.	1 for mentioning concept 2 for explanation 5 for novel application
17	Wait	A `wait` command is executed by a process that is trying to access an already locked resource. The process is willing to wait until the resource is available and is put in a queue of processes waiting for access to the resource. On a `wait` command, the operating system checks the lock status of the resource.	1 for mentioning concept 2 for explanation 5 for novel application
18	Signal	A **signal** operation tells the operating system that a resource has been released from an atomic action. A process executing a **signal** operation has finished using the resource. The operating system will record that the resource is available and one of the processes waiting to access it will be activated.	1 for mentioning concept 2 for explanation 5 for novel application
19	Queue	An order in which those requesting a resource wait for it if it is unavailable at the time they make the request.	1 for mentioning concept 3 for explanation 5 for novel application

20	Wake	Activating a process in a queue. (The operating system issues a **`wake`** when managing the queue)		1 for mentioning concept 3 for explanation 5 for novel application
Total	15 for identifying concepts	45 for explanations + 2 for reproductions	100 for novel applications	Overall total of 167