Diagram Representation: The Cognitive Basis for Understanding Animation in Education

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Dedication

I would like to dedicate this thesis in memory of my supervisor

Dr. Mike Scaife

who has, since the submission of this thesis, tragically died.

I feel extremely privileged to have known Mike and to have experienced the benefit of his inspiration, astute sensitivity and wonderful powers of insight.

Mike, for whom I had the deepest respect, will be greatly missed.

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Summary

Recent developments in computer technology provide exciting, innovative ways of representing and interacting with information, bringing new perspectives on learning with multimedia. Animated diagrams are one form of (graphical) representation being increasingly used in multimedia contexts, with underlying assumptions about their educational benefits.

Previous research suggests that diagrams can facilitate understanding, as information is more visually explicit, requires less inference recognition than sentential representations, and constrains inferences, which can guide cognitive processing. Thus, the visual explicitness of motion inherent in an animated diagram should also reduce cognitive processing and aid understanding of dynamics. However, facilitation of cognition results from particular properties integral to the static representation, and although some of these properties may apply to animated diagrams, research suggests that underlying differences in the fundamental form of an animated representation, may generate different cognitive outcomes, making these benefits less apparent.

This research focuses on cognitive interaction with animated graphics by investigating the effects of fundamental properties of animation on cognition. A comparative study using animated and static graphics of a dynamic system, is used as a basis for collecting information about potential learning models and properties specific to animated representations. Three groups of properties are identified, and a model of learning with an animated diagram in relation to these graphical properties is proposed. With these perspectives as a basis, a series of studies investigates the cognitive interaction needed with an animated diagram by pupils studying dynamic processes.

The results from these studies suggest that initial assumptions about the cognitive benefits of animation are unclear, but they do show evidence of patterns in cognitive processing of dynamic information. This provides the basis for generating an preliminary cognitive model

for processing graphical change from animated diagrams. This model serves as a starting point for further research and for informing particular aspects of diagram design.

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Chapter 1

Aims and Structure of Thesis

1.1. Introduction

Investigation into the literature on diagrams has revealed limited current knowledge of the cognitive value of graphical representation, and many assumptions that multimedia and more advanced technology result in improved learning (Scaife and Rogers 1996). Advances in graphical technology have enabled more varied and dynamic illustration of concepts, for example, the use of animated videos and computer animation to show motion and dynamics more explicitly. This, together with increased computer facilities within schools, highlights the importance of investigating whether educational software, in this form, can be instructionally advantageous, and how diagram design can generate optimum learning. Research into the use of animation for learning is inconclusive and claims for its value for depicting dynamics requires further investigation, particularly in terms of the cognitive effect of using animation to depict dynamics, by investigating the cognitive processes underlying the use of animation.

1.2. Aims of thesis

This thesis set out to explore the cognitive effects of using animated diagrams to depict dynamic processes, the main focus of the research being to begin to identify components of a cognitive processing model of animation. Thus, the research investigates the effectiveness of animation in facilitating the learning and understanding of domains concerned with dynamic processes or systems. How do learners read information from animated diagrams? What pieces of information do they pick out from the animation? What kind of meanings do they infer from the animation? How do they integrate these pieces of information with previous knowledge and with the material they are currently using?

To achieve this goal certain aspects were developed during the research in order to assemble information that would explicate a cognitive model of processing animated diagrams.

- Devising an analytical framework for examining underlying cognition when using animated diagrams for learning about dynamic processes. The framework devised focuses on particular representational properties of animation together with proposed appropriate learning stages to examine the way that these properties may influence learning.
- Realising a suitable methodology for extracting aspects of cognitive processing when working with animation in order to construct a model of learning with animation.
- Designing and creating suitable animations for the purposes of this research.
- Determining outcome measures appropriate for informing about specific cognitive aspects of a processing model as well as providing learning outcomes.

Several studies were then undertaken to explore the cognitive effectiveness of animation. A brief overview of each chapter is presented here.

1.3. Chapter 2: Literature Review

The literature review in this thesis focuses on literature particularly relevant to the research in this thesis. This comprises three main sections:

- Section one covers previous research on the cognitive benefits of diagrammatic representation, and the implications of these findings in terms of assumptions of potential benefits of animation for learning. Previous research investigating the learning effects of using animation is discussed in relation to its contribution to the proposed research in this thesis.
- Section two presents work that contributes to the theoretical and analytical framework used in the thesis, which comprises the Cognitive Interactivity framework (Scaife and Rogers 1996) and the Cognitive Dimensions framework (Green 1989, 1991). This section also includes relevant research on animation that contributes to the theoretical and analytical basis of the research undertaken here.
- Section three discusses particular aspects of research relating to cognitive models, considered appropriate for identifying ways and levels of constructing a processing model of animation.

1.4. Chapter 3: Theoretical Rationale and Methodology

This chapter is also divided into three main sections;

- Section 1 defines the problem space of the thesis, and presents the theoretical rationale for the studies undertaken. The particular properties and features of animated representations are identified as a basis for the investigations in this thesis, namely, multidimensionality, transience, and graphical change.
- Section 2 describes a proposed learning model using animation in order that relevant cognitive activities when interacting with animation can be investigated.
- Section 3 addresses methodological issues for this particular research, giving reasons for the design of materials and methods used in the studies presented here.

1.5. Chapter 4: Diagram Representation: A comparison of animated and static formats

This chapter presents the first study of the thesis, and compared learning of a dynamic system from either an animated or a static representation, and explored the effects of structuring versus not structuring information while learning with diagrams. This study served several functions;

- It provided base line information about the benefits and disadvantages of learning with animation, as well as clarifying some properties particular to animated representations that may affect cognitive processing with this kind of representation. These findings were implemented in subsequent studies.
- The results showed that structured information facilitated learning regardless of the representation. This provided both a basis for and the rationale behind the design of later studies investigating integration of information from animated diagrams.
- It raised important issues about the particular design of materials in terms of their appropriateness for this research. This first study used an animation from 'What's the Secret' CD ROM. This meant that, although suitable for comparing animated and static representations by taking screen dumps, it would not be suitable for further investigation which required manipulation of the design, presentation or interactivity opportunities with the animation. Therefore, the materials for subsequent studies were adapted accordingly.

1.6. Chapter 5: Research Modifications

This chapter summarises the problems associated with materials used in the previous study in relation to the aims of the thesis, and explains the design and creation of alternative animations using Macromedia Director. Animations of the heart and circulatory system, and of gas exchange during respiration were specifically developed for the purpose of further investigations into the cognitive effectiveness of animation. Clarification is provided of the issues to be explored in the next series of studies, in terms of the representational features of animation (defined in detail) and proposed stages of learning, as the following studies focused more specifically on cognitive interaction with the dynamic properties peculiar to animated diagrams, such as identifying and interpreting graphical change, and integrating different pieces of information from the animation. The methodologies adopted for the following studies generated both qualitative and quantitative data, enabling detailed descriptions and experimental evidence of learner understanding. Thus, in some studies a small number of pupils gave concurrent verbal protocols while working with the animations, and in other studies a larger group of pupils completed written and/or diagram post tests after working alone with the animations.

1.7. Chapter 6: Dynamic parsing: The effect of dynamics on salience and interpretation of graphical change; A case study.

Chapter six explores ways in which graphical change (an inherent property of animation) is identified and interpreted according to levels of complexity of the animation defined in terms of memory load due to transience and multidimensionality of the representation. The primary focus of the study was to investigate the visibility of each graphical change taking place on the diagram, in terms of its salience and interpreted meaning. This study took the form of a case study with pupils working in pairs and with the researcher. Data collected was primarily verbal protocols and interview data, but pupils also completed a written post test. For analysis graphical change was classified according to type of change (extrinsic or intrinsic). Evidence from the case study suggested that certain types of graphical change were more salient than others, and that interpretation was affected by the perception of the type of graphical change that occurs. The pattern of processing was also potentially affected by an issue which arose unexpectedly from these studies relating to learner expertise in terms of level of prior knowledge. The findings here confirm previous research showing that levels of prior knowledge influence the way that information may be processed from the animation.

1.8. Chapter 7: Dynamic parsing: The effect of dynamics on salience and interpretation of graphical change; An experimental study.

Chapter seven describes an experimental study investigating more rigorously the cognitive processing involved in reading graphical change from an animation. The experimental design consisted of three different levels of viewing each animation according to the number of runs seen (minimum number (1), intermediate number (2 or 3 depending on animation) and maximum number (4 or 5 depending on animation)). The findings of the studies in chapters six and seven suggest evidence for the following: *(i)* a new dimension of graphical change was identified, termed feature presence, *(ii)* the importance of interpretability as well as visibility of graphical change in understanding the animated diagram, *(iii)* the interaction of identification and interpretation of graphical change significantly affects understanding from the animation, *(iv)* the different types of graphical change are processed differently and may be affected by certain features of the representation, and *(v)* some prior knowledge facilitates initial identification and interpretation of graphical change.

1.9. Chapter 8: Processing animation: How information is integrated from a dynamic representation.

Although perception and interpretation of graphical change are important in retrieving appropriate information from an animation, understanding is also dependent on integrating those pieces of information into a coherent whole. Therefore, the primary focus of the studies in chapter eight was to investigate the kinds of links that pupils made between different pieces of information from the diagram. However, research into 'reading' be it text, speech or diagrams, shows that information is generally parsed in order to make sense of it, and Green (1989) highlights the importance of parsability as a cognitive dimension of notation. The form of animation results in high dynamic information load and transience, both of which affect focus of attention, demanding the need for parsing the representation. To investigate how learners make links and the effects of parsing, this study used an animation that was parsed into smaller sections and presented in two different ways. The study showed that the presentational format of the animation significantly affected learning, and that explicit links between pieces of information are important in facilitating understanding. This reveals that not only is parsability important in integrating information, but also the linkability of pieces of information in the representation.

1.10. Chapter 9: General Discussion

The aim of this thesis was to explore ways of investigating the cognitive effectiveness of animation, with the ultimate aim of beginning to describe a cognitive model of processing animation at some level. Therefore, this chapter begins by summarising the results of each of the studies in this thesis in terms of evidence for cognitive processing accounts. The findings are then discussed in relation to the effect on cognition of features, identified in this thesis, of the representation and the learner (i.e. multidimensionality, transience, prior knowledge). The chapter goes on to identify and define features as Cognitive Dimensions of animation, and to propose a cognitive model of understanding animation. The research in this thesis hopefully provides the beginnings of a workable analytical framework (focusing on the interaction between representational properties and learning demands) and some evidence to contribute towards the start of a description of a processing model of animation. However, there is much further valuable work to be pursued in this research area, some of which is mapped out in this final chapter.

Chapter 2

Literature Review

2.1. Introduction

Chapter one briefly outlined the problem space and aims of this thesis to explore learning of dynamic processes using animated diagrams with the ultimate aim of identifying cognitive components of a processing model of animation. The literature review, therefore, concentrates on three main areas of research relevant to the research undertaken in this thesis. Section one begins by placing animation within the realms of other research on external representations, and then introduces a large body of research work to date on the benefits or not of using computer animation as well as explaining the implications of those studies in terms of this current research. The main drawbacks of the majority of previous research on animation are explicated in relation to the aims of this thesis, although some research more directly related to the aims of this thesis will be reviewed in more detail within sections two and three. Section two presents research on external representations that provides a basis for developing an appropriate analytical framework for establishing the effectiveness of animation in terms of the particular properties of the representation. Section three identifies principal theories of cognitive modelling and research for defining an appropriate level of description for this research in striving to begin to develop a cognitive model description of processing animation.

2.2. External representations and diagrams

2.2.1.External representations

- Definition

Research into human cognition has shown the value of external representations for memory aids and processing information. External representations refer to representations that are external to the mind, and are a way of re-presenting some kind of information. External representations are primarily visual representations of information expressed through the use of physical symbols. Making notches in sticks would be an historical example of an external memory aid for remembering or calculating. External representational forms have evolved over time and are, therefore, historically and socially situated tools for cognition (Seeger 1999). One important form of external representation is graphical representations comprising for example, maps, diagrams, graphs, tables. These representations are tools that can be used, for example, to aid problem solving, learning, teaching, and therefore serve a functional role in cognitive processing.

- Benefits of external representations

Generally external representation can serve as an aid to cognition in that information needs not be held internally while using, or thinking with, that particular information. One of the benefits of this is that it reduces memory load. A shopping list or a diary might be good examples of the effectiveness of external representations in doing just this. Earlier research on external representations focused on linguistic representations and led to the development of, for example, cognitive models of reading (e.g. Rumelhart's (1994) Interactive Model of Reading). However, research into graphical external representations has more recently become prominent, investigating ways in which information from this kind of representation is processed. This has demonstrated that external graphical representations can be beneficial for learning, or problem solving (e.g. Larkin and Simon 1987, Bauer and Johnson-Laird 1993, Zhang and Norman 1994).

- Relevance of understanding external representations work to this research

However, more than just finding out the benefits of external representations, we need to know how external representations work in terms of both their cognitive benefits and disadvantages in order to construct a cognitive processing model. Achieving this would provide information towards a more detailed theory of cognition. This research involves investigation of the use of animated diagrams (one form of external representation) for aiding cognition, understanding, and /or learning in an educational context, with the purpose of beginning to define a cognitive model of processing such representations.

2.2.2. Diagrams

Diagrams are one form of external representation and are graphical forms of conveying information, used extensively in educational contexts across the curriculum. Diagrams come in many different forms and kinds making classification of this group of external representations problematic. Although attempts have been made to classify diagrams into relevant groupings, the problem of classification in relation to research into the effectiveness of diagrammatic representation has been highlighted, because it decreases the generalisability of results across diagrams in general (Cheng, Lowe and Scaife 1999). Although several researchers have attempted to create a taxonomy of diagrams at differing levels of description (e.g. Hegarty et. al 1991, Lohse et al 1991, 1994, Cox 1996, Blackwell and Engelhardt 1998), at a general level Winn (1987) defined a functional difference between graphic forms, such as charts and graphs, and diagrams; the function of graphs and charts is to show simple relationships between variables, whereas "the function of diagrams is to describe whole processes and structures often at levels of great complexity" (Winn 1987, p. 153). Despite this classification problem, previous research into diagrams suggests various ways in which they may be cognitively beneficial.

- Cognitive benefits of diagrams

Much research into the use of diagrams has provided evidence for the benefits of such external representations. A diagram can support cognitive processing generally, by acting as an 'external aid to thought' (Addis 1997), but has also been found to ease processing or reasoning and problem solving. The diagrammatic form itself provides the facility to describe whole processes and structures, often at levels of great complexity (Winn 1987) in one representation. This representational capacity of diagrams has been shown to be cognitively beneficial in several ways;

(i) Simultaneous presentation of information

Larkin and Simon (1987) argue that diagrams offer several pieces of information simultaneously, unlike text which is sequential in processing. This precludes the need to unite separate facts to comprehend a whole concept, therefore reducing cognitive processing.

(ii) Perceptual availability of information

The perceptual availability of information from a diagram may also reduce cognitive processing due to explicit representation of the topological and geometric aspects of a problem (Larkin and Simon 1987). Larkin and Simon express a fundamental difference between sentential and diagrammatic representations as the "diagrammatic representation preserves explicitly the information about the topological and geometric relations among components of the problem, while the sentential representation does not" (1987, p.66). This means that many important aspects for comprehension are visually explicit in the diagram, precluding the need to 'work out' some aspects, such as relational components (Larkin and Simon 1987). Visual explicitness also facilitates search ease and can result in less need for making inferences. "Formally producing perceptual elements does most of the work of solving the geometry problem. But we have a mechanism – the eye and the diagram – that produces exactly these 'perceptual' results with little effort" (p.92). "It is exactly because a diagram 'produces' all the elements 'for free' that it is so useful." (Larkin and Simon 1987, p.92).

(iii) Reduction in memory load

Facilitating deductive reasoning was also evident from using diagrams in research by Bauer and Johnson Laird (1993). This study showed that certain diagrams mean that all the computation does not need to take place in participants minds, but they can solve problems and make inferences by using an external representation as a cognitive support. Hegarty and Kozhevenikov (1999) have also found that learners used external diagrammatic symbols to 'offload' information, as a strategy to reduce memory load.

(iv) Inference constraining

Further research into the use of diagrams has shown more specifically that, although diagrams have visually explicit properties that can facilitate problem solving, the use of a diagram per se is not always necessarily beneficial, as the particular way in which the information is represented diagrammatically also influences the degree to which cognitive processing is reduced. For example, Zhang and Norman (1994) showed that different representations of the same problem structure resulted in different amounts of computational offloading (the degree to which diagrams provide cognitive benefit by reducing cognitive processing) according to the number of implicit and explicit rules within the diagram composition. The level of cognitive benefit increased with the increase in the number of implicit rules, an implicit rule being one that constrains the way in which a problem can be solved, due to the representation. Diagrams can, therefore, facilitate understanding, as information is more visually explicit, requires less inference recognition than sentential representations, and because components of the diagram which constrain inferences can guide and "even determine the pattern of cognitive behaviour" (Zhang 1997, p184). Euler's circles are also an example of this, where the representational properties constrain inferences that can be made about the elements in each circle (Stenning and Oberlander 1995) .

2.2.3. Summary

Diagrams, then, can make important aspects of information salient and facilitate "perceptual parsing and inferencing through directing attention to key components that are essential for different stages of.....learning" (Scaife and Rogers 1996, p. 207), and constructively constrain inferences. Diagrams should, therefore, facilitate understanding, as information is more explicit and requires less inference recognition. One of the overriding factors in benefits of diagrams to cognition is the visual explicitness of the representation. This factor is particularly relevant because it suggests that visual explicitness, one representational space etc.. all aid cognitive processing and ease problem solving or reasoning. It may therefore be reasonable to make the assumption that as animated diagrams show dynamics more visually explicitly, diagrammatic animation of dynamic processes will aid cognition and facilitate understanding of dynamic processes.

2.3. Animation research

2.3.1. Assumptions about animation

Diagram research demonstrates the benefits of external representations due to visual explicitness and perceptual availability, resulting in computational offloading. These findings may contribute to assumptions about the benefits of animation, particularly animated diagrams and result in misplaced inferences about cognition and learning with animated representations. On the basis of findings from research about diagrams, it could be argued that if visual explicitness and the perceptual availability of information from a diagram reduce cognitive processing, then the visual explicitness of change (e.g. motion) inherent in an animated diagram should also reduce cognitive processing and facilitate understanding of dynamics. However, assumptions that animations are as beneficial for cognitive processing as diagrams generally, may be misplaced. Even though dynamic information is more explicitly displayed, what is true of a static diagram may not necessarily be true of an animated diagram. For example, the cognitive benefits of diagrams as cited by Larkin and Simon (1987) are based on the defined difference in data structure between sentential and diagrammatic representation. Sentential data structure has elements which "appear in a single sequence", whereas diagrammatic data structure has "information which is indexed by two dimensional location" (1987). However, a diagram that is animated has both of these data structures, in that not only is information linked by two dimensional location (the components of the diagram), but also the process being depicted is similar to a sentential data structure in that the information (dynamic) appears in a sequence. So the claim that a major benefit of diagrams is that they can group together all information that is used avoiding large amounts of search for elements (cited Koedinger 1992) may not hold true for animated diagrams, where multiple diagrams (an inherent property of animation) increase the amount of search and integration of information across the whole sequence of images.

2.3.2. Previous animation research

Over the last two decades several studies have investigated the effects of diagrammatic animation on learning. However, the research into the use of animation in education has generally resulted in inconsistent findings, not only in terms of whether or not animation is beneficial to learning, but also in terms of the specific factors that may influence those cognitive benefits or disadvantages. Some research has shown animation to be beneficial in some learning situations, others have not. The effectiveness of this research in relation to this thesis is discussed below.

- Benefits of animation

Despite the inconsistency of the research several studies have shown animation to be generally beneficial to learning and some have drawn specific relevant conclusions regarding aspects of the design and use of computer animation. In Szabo's (1997) review of 22 experimental studies, 11 were cited to show full or partial significant effects in favour of animation (i.e. Alesandrini 1982, Alesandrini & Rigney 1981, Baek & Lane 1988, Carpenter and Just 1992, Collins Adams & Pew 1978, Kaiser Profitt Whelan & Hecht 1992, Mayton 1991, Rieber & Boyce 1990, Rigney and Lutz 1976, Szabo & Poohkay 1996). However, further studies have also shown conditions under which animation was found to beneficial (i.e. Rieber 1989, Thompson & Riding 1990, Rieber 1991, Mayer 1991, Mayer & Anderson 1992, Kieras 1992, Large et al 1995, Hays 1996, Lowe 1996, Nicholls, Merkel, Cordts 1996). However, several studies investigating the benefits of animation for learning showed no significant effects for animation. (e.g. King 1975, Peters & Daiker 1982, McClosky & Kohl 1983, Reed 1985, Caraballo 1985, Doll 1986, Rieber & Hannafin 1988, Park 1998, Rieber 1990, Szabo & Schlender 1996, Dahlquist 1997, 2000). Although studies do not necessarily show a positive learning effect for animation, studies generally did not indicate detrimental effects (e.g. Park and Hopkins 1993, Guttormsen Schar and Krueger 2001). Although taken collectively, particular benefits or disadvantages of animation were not uniformly found across the studies, making specific conclusions difficult to draw, some groupings of findings can be identified.

(i) Partial benefits

Sometimes benefits found were only partial, for example, Rieber and Boyce (1990) investigated the effectiveness of animated as oppose to static graphics or no graphics on understanding of Newton's laws of motion and found no difference between groups in the amount learned, but did find that those using animation retrieved learned information quicker than those using a static or no diagram.

(ii) Benefits for particular kinds of learning

Some studies showed benefits for particular kinds of learning only, for example, Rieber (1991) found animation improved performance (over static or no graphics) for incidental learning, and Large (1995) showed animation to benefit procedural learning. These kinds of benefits may be a product of congruency of the relationship between the learning task and the animation. For example, in Rieber's (1991) study comparing animated and static graphics of Newton's laws of motion incidental learning was possible from the content implied by animation only.

(iii) Subject groups

Benefits of using animation were shown to be evident for particular subject groups, for example Hays (1996) found animation improved performance for lower spatial ability individuals, but this was only apparent in contexts where understanding of a process involved dynamic or spatial processes. Rieber (1989) found animation improved performance for children learning about Newton's laws of motion, but not for adults (1990).

(v) Design aspects

The potential benefits of animation have also been shown to be enhanced when used in combination with other media. Mayer's (1991, 1992) work on the use of verbal narration or text in conjunction with animation, showed that understanding concepts using animation was significantly improved if verbal explanation ran concurrently with the animation. "Students learn best when words and pictures of an explanation are presented contiguously in time and space" (Mayer and Anderson 1992, p.450). However, Large (1994, 1995, 1996) also investigated the effect of animation on textual information, with several studies showing that "any relationship between animation and learning is subtle and dependent upon the presence of other factors. The animation must be well integrated with the external content and must be presented in a suitable way for target audience. A complex text cannot be rendered more accessible by supplementing it with a complex animation." (1996, p.527). This is important in informing the design of animation in terms of the accompanying information, for example, what and how it is delivered. However, it does not inform us if, and how, the animation itself may be beneficial in imparting dynamic information, as oppose to static representations or verbal narration or text. The representational design of the animation has also been shown to affect whether animation is beneficial or not to understanding. Kaiser et al. (1992) completed a series of studies investigating the use of animation on people's perception and understanding of mechanics. They found that animation was beneficial when the representation showed unidimensional dynamics (only one dynamic event) as oppose to multidimensional dynamics (Kaiser et. al. 1992).

(vi) Representational features

Animation has also been cited to be beneficial in terms of its representational features, for example, Park (1998) found that animation was a more effective visual tool than static graphics when the entity depicted is itself an animated event or object. Park (1998) also maintains that animation provides several important instructional roles, such as attracting and directing attention, to represent domain knowledge involving movement and in explaining complex knowledge phenomena, e.g. structural and functional relationships among system components. Jones and Scaife (2000) also found benefits which related to the explicit depiction of motional aspects, i.e. information about dynamic changes, temporal relational aspects (e.g. learners could construct clearer models about how the valves worked and how the heart 'pumped'). This motional characteristic of animation is generally perceived to potentially enrich learning (Large 1994).

- Summary of previous research

In summary, then previous research into animation consists of a multitude of studies investigating whether or not animation is beneficial to learning in a general sense within each of the particular domains, conditions, subject groups etc.. of the study undertaken. This makes integration of the research findings into any coherent understanding of the use of animation in education unrealistic and therefore, findings from animation research is inconclusive.

2.3.3. Reasons for inconclusiveness of animation research

The inconclusiveness of previous research has been commented on by several other reviewers (e.g. Large 1996, Park 1998, Betrancourt & Tversky 2000) who suggest that these problems arise from the diversity of potential research factors and variables within the field of animation in education resulting in vast differentiation between studies (Betrancourt & Tversky 2000), and from methodological and theoretical problems of this research area (Park 1998). Although many of these methodological problems may apply to other research areas within education and learning, they are presented here in relation to research on animation, followed by a discussion on the further drawbacks of primarily focusing on comparative studies (comparing general learning between different representational formats) for uncovering particular benefits or disadvantages of using animation.

(i) Domain space

A large array of different domains have been used for experimental investigation makes generalisations to other domains difficult. For example, physics (e.g. Rieber 1990, Dahlqvist 1997), biology (e.g. Mayer and Sims 1994, Hays 1996), economics (e.g. Grimes and Whiley 1996), weather understanding (e.g. Lowe 1994, 1996). Some of these studies showed learning benefits while others did not, and those that did generally cited variables other than those specific to animation affecting the outcome, for example, spatial ability (Hays 1996), with the exception of Lowe (1996). This study showed a focus on the specific effects of animation in interpreting the diagram, finding that animation increased the ability to detect gross pattern changes on the display.

(ii) Participants

Different subject groups were used in different experiments, again reducing the opportunity to generalise results. However, studies do indicate that children respond differently from adults to animation (Rieber 1989, 1991), and may therefore process this kind of information differently. However, it is unclear whether this difference is a developmental difference or difference in expertise. Other studies indicate potential differences in spatial ability, which may have some bearing on the effectiveness of animation, but requires further research.

(iii) Individual differences

Participants in different studies varied in terms of their expertise with using such diagrams, their motivation, their level of prior knowledge, their spatial ability, all of which will affect the ways in which they interact with different kinds of representational formats. For example, expertise at 'reading' animation may facilitate the ability to retrieve certain kinds of information from the display, which is unavailable to novice animation 'readers'. Expertise within the domain of the animated representation may also facilitate information retrieval and it has in fact been well researched that differences exist in the way information is perceived and understood according to the level of expertise of the learner/user, due to the effect of their internal representations on the way they interact with the diagram (e.g. De Groot 1965, Hinsley et. al 1977, Egan and Schwartz 1979, Ehrlich and Soloway 1984, Lowe 1994).

Spatial ability also has been found to affect understanding of dynamic systems. Hegarty et al (1999) investigated understanding of motion through the use of mental animation, i.e. the ability to infer motion from static diagrams, in terms of mental model construction of movement. Understanding was shown to be related to individual spatial ability and the type of system or diagram used in terms of its complexity (one moving component or several components moving simultaneously). In these studies learners were required to mentally simulate movement of a system, thus requiring them to 'work out' the dynamics. By contrast, providing explicit visual representation of motion (through animated diagrams) precludes the need to 'work out' dynamical aspects. The effect of this 'provision' of such images on learning (animation), therefore, requires further investigation.

(iv) Task differences and outcome measures

Studies have also differed in the learning tasks and subsequent learning outcome measures used, therefore targeting different kinds and aspects of learning. For example, Mayer and Anderson (1992) focused on problem solving ability, Williamson and Abraham (1995) on conceptual understanding interacting with student reason ability, whereas Large et. al's (1995) study involved procedural learning, and Rieber's (1991) study comprised incidental learning. Although these studies provide information about the use of animation in certain learning situations with certain kinds of tasks, they provide little information about how or what feature of the animation assists or not the learning that takes place.

(v) Different measures

Research has also been criticised for the differences in outcome variables used, (from recall to problem transfer tests, using verbal or written tests, descriptive or multiple choice questions), as well as differences in time lag between testing and viewing (e.g. Large 1994). Several researchers focused on immediate post testing, whereas delayed testing may provide more information on the implications of the research. For example, Mayton (1991) found animation to be beneficial in adults, the effects of which persisted one week later. However, there seems to be no uniform agreement on appropriate time delays for testing.

(vi) Representation design

The particular design of the representations used may also affect learning outcomes. Some of the research findings cited above could be related to particular design of the representational formats used, for example, Park's (1998) study showed no significant differences between animated and static diagrams when the static diagram contained appropriate motion cues. Not only may the design of the static or textual information affect results, but also the particular design of the animation itself.

2.3.4. Further issues relating to previous research

Although, these methodological problems may be generally applicable to research in this kind of area, there are further problems for research into animation due to the primary focus of the majority of studies. They predominantly concentrate on *(i)* general learning outcomes, which detracts from examining particular features of the representational formats in terms of their specific cognitive advantages and disadvantages, and *(ii)* on comparisons between different representational formats (e.g. static diagrams versus animated, text versus animation), which open the studies up to several additional drawbacks.

- Information equivalence

To make a beneficial comparison between different representational formats it is desirable that they are informationally equivalent, as far as is possible. Several experiments investigating the effectiveness of different diagrammatic representation do not guarantee information equivalence between the different representational formats used. Thus, any benefits from the representations cannot necessarily be attributed to cognitive or computational properties, but may be due to one representation containing more information than another (Cheng, Lowe & Scaife 2001), making it impossible to draw conclusions from multiple studies on animations (Morrison and Tversky 2000). The concept of informational equivalence can occur on different levels: the ‘equivalence’ of the media of the representation (paper or computer) (Pane, Corbett and John 1996) or the ‘equivalence’ of the information contained in each of the diagrams. Simon and Larkin (1987) define information as equivalent when all information provided by one representation is inferable from the other and vice versa. However, they also make a distinction between this and computational equivalence, which is present when representations are informationally equivalent *and* any inference that can be drawn quickly and easily from one can be drawn as quickly and easily from the other. However, it is debatable whether information in one representation can ever be truly equivalent to that of another representation in a different format. The very fact that it is presented in a different way may alter the information that is imparted, and will certainly alter the *way* in which it is imparted. This in turn will also influence the specific aspect(s) of the information that is imparted. In this way then information cannot, strictly speaking, be said to be equivalent from one representation to another. For example, when looking at animated diagrams and static diagrams, the depiction of a diagram could be identical in terms of the graphics used, the colour, the dimensions, the outline, the components, the text accompanying the diagram, but as soon as one representation is animated the information imparted is no longer equivalent to the information imparted from the static diagram. This, then poses a problem when comparing animated and static diagrams if information equivalence is to be realised.

- Comparisons of different kinds of representations or different teaching situations?

The majority of the previous studies investigating the value of animation come from differing viewpoints, for example, comparisons between static and animated versions of the same or similar information or comparisons between text and animation. Large’s (1996) review of animation states that much research has “centred on whether the addition of animation enhances educational value of text” (p.9). In investigating this other variables likely to affect learning outcomes automatically come into play, such as the type of text (narrative, descriptive) the complexity of the text (based on different reading levels) and the length or layout of the text. This then becomes research into the value of animation interacting with text resulting in studies potentially specifying benefits with one type of text but not another, and detracting from the effectiveness of animation per se.

Other reviewers have generalised results across studies that compare animated and static with studies that compared CAL (Computer Assisted Learning) with regular teaching (Betrancourt and Tversky 2000). But again the additional variables affecting learning are potentially huge, and isolating the effects of animation particularly must be virtually impossible. For example, CAL offers more different media and other teaching input than using one particular representational format. Therefore, although CAL might contain animation, the benefits of one learning situation over another cannot be attributed to the animation per se. Overall comparative studies have the effect of assessing learning in particular situations about particular topics, but do not address the issues related to how and in what ways animation affects cognition, be it beneficial or detrimental.

Animation has also been noted for its qualities of 'attraction' (e.g. Park 1998). Therefore, when making comparisons across representational formats or even different teaching situations, the animation may detract attention from text or other media, resulting in a potential imbalance in attention to the material presented. Again this reduces the conclusions that can feasibly be drawn about the specific effectiveness or not of animation.

- Underlying cognition

Studies investigating comparative differences in learning show mixed results; sometimes static representations are beneficial over animated, sometimes animated are beneficial over static, or there are no significant differences between the two. However, much of the previous research comparing the effects of animated with static or textual representations focuses on fairly general learning outcomes, rather than on the underlying cognitive processing leading to that learning. Straight comparisons of learning outcomes in terms of amount of knowledge acquired gives little information about the particular usefulness of animation. Although, some research has begun to point to some issues relevant for further research into the cognitive effectiveness of animation, such as, attracting and directing attention, explaining complex phenomena and dynamic systems (Park 1998), proposed benefits for low prior knowledge and high spatial ability pupils (Mayer 1997), and aiding construction of mental models (Park and Gittelman 1995), the specific mechanisms remain undefined. It is unclear as to what kind of information attention is attracted and directed to. Is it the overall moving image, or individual components or the dynamic events themselves? It is also unclear whether effective 'explaining' of phenomena is effective for eliciting adequate comprehension. Animation may be beneficial for different individuals in terms of spatial ability or prior knowledge, and in constructing mental models, but there is as yet no clear understanding in what ways animation facilitates processing in these circumstances. There is little specific evidence indicating when animation is valuable, what aspects of animation are valuable, or indeed when and under what circumstances animation may be detrimental to learning. It is uncovering the more detail of this underlying processing that is important in informing how animation may or may not be beneficial to learning.

2.3.5. Summary of research

Varied use of different methodologies and variables make generalisations about the findings of the effectiveness of animation difficult. Results across studies are therefore inconsistent or domain/ task / user specific. It seems that, not surprisingly, animation is sometimes beneficial and sometimes not to understanding or learning. Overall learning comparisons offer an indication that one representation might be better than another in a given circumstance, but offer no indication as to how or why. Comparison of different formats may however be useful if differences in the kinds of learning that take place are unfolded, rather than an overall learning comparison. If particular differences in learning can be identified this would then provide bases for locating where animation may be most beneficial and/or most hindering to learning (Jones and Scaife 1999). Furthermore, this information can then be used as a basis from which to examine particular aspects or properties of animated diagrams that are different from static diagrams and that may be beneficial to learning.

Thus, previous research has served to emphasise the underlying complexity of researching the cognitive effectiveness of animation and the need for further more systematic investigation, and a more general analytical framework within which learning with animation can be investigated. This research tries to address this by taking and examining the effects of the underlying representational properties of animation on cognition (see 2.4. below) to discover what it is about animation that makes it easier or more difficult to understand, what are the properties of animation that render it one thing or another.

2.3.6. Problems with assumptions about animation

From research into the learning effects of animation it is apparent that assumptions that may have been made about the cognitive benefits of animation (as a result of conclusions of diagrams research generally), may not necessarily hold true. Although, animation may depict dynamic events or aspects more visually explicitly the form of animation itself may detract from the potential benefits of this explicitness. Certain properties of representations have been cited to potentially generate cognitive complexities for the user. Stenning (1998), for example, proposes that animation results in complexity for the learner and may be a consequence of the following characteristics of animation; i) evanescence, the problem of memory load is enhanced by the 'transient form' of animation. Animation consists of a sequence of fleeting images, which pass by, are not persistent, which means that all sequences of movement need to be held in memory to integrate with new pieces of information to understand the process; ii) control, the evanescent form means that learners are unable to reaccess pieces of information from the animation as they are no longer perceptually available. Learners therefore have no control over what information is viewed, or for how long, as the information is continuously passing by. Kaiser et al. (1992) investigating understanding of mechanics found that where only one dimension of the dynamic information was present then animation facilitated accurate observation. This suggests that 'parsing' of dynamic events is important in facilitating correct dynamical judgement. One factor that may influence this is the focus of attention of the learner on the dynamic event, or even the amount of effort invested on the half of the learner in processing the information. The provision of a visual depiction of dynamics may prevent learners from investing cognitive effort, reducing the level of learning taking place (Hannafin and Phillips 1987).

Thus, there are indications from other research that the properties of animation that go hand in hand with visual explicit depiction of dynamics, may not automatically be cognitively beneficial through perceptual availability and computational offloading. The interaction of these kinds of cognitive effects with the particular representational format may have different outcomes from those discovered for static diagrams.

2.3.7. Implications for this research

Generally speaking previous research into animation offers small snippets of useful information in relation to the benefits or not of animation, and provides one or two clear proposals for the design of these graphics in learning situations. For example, the benefits of providing verbal explanation contiguously with the animation, and providing appropriate motion cues on static information presentations of dynamic systems or processes. However, the research generally does not reveal any significant information about the specific cognitive processing involved in reading animated diagrams nor does it provide sufficient theoretical grounding for further research into the use of animation for learning. Very little research has explored *how* animation may be beneficial for learning. Studies have mostly looked at the general effects on learning with animated representations, more often than not in comparison with static presentations of the same information. Studies have also focused to large degree on variables such as task, domain, individual differences, training, particular learning outcomes, rather than focusing on the cognitive processing that occurs when interacting with an animated diagram. Although these studies may give some indication of the comparative value of animation for particular domains and for particular subject groups, they do not provide information on *how* the animation is cognitively beneficial or detrimental to learning. The question of the ways in which animation may or may not facilitate learning has not been comprehensively addressed. As a result no systematic way has been developed for investigating the effectiveness of animation for learning. What is needed is a more detailed account of how processing occurs when using animation, not just instances of improved general learning outcomes. The focus of research needs to be more directed at what it is that makes an animation an animation and the cognition involved in reading this kind of representation.

One way to obtain information about the cognitive effectiveness of diagrams would be to investigate them on a more specific level in terms of the representational properties or characteristics of the diagram. Thus, the form and features particular to animation need to be identified and the effects of these examined at a more specific level. For example, by exploring the effect of explicit depiction of graphical change on understanding. This would enable clearer conclusions to be drawn about the effectiveness or not of representing dynamics through animation. Furthermore, if information is procured that shows the cognitive effect of specific properties of animation then this information may be generalisable to other domains and situations where the same representational properties are present. This thesis attempts to define a way of evaluating animation that enables more generalisation across studies, by focusing on inherent properties of the representation and examining the effect of these on learning about a dynamic process.

By focusing on the cognitive interaction with properties of the representation the thesis is also able to explore ways in which information is processed. This should provide clearer information about the cognitive effectiveness of animation as “the processes that evaluate and interpret the representations are as important as the representations themselves” Rumelhart and Norman (1987, p. 20). Thus, the research in this thesis is also an attempt to begin the development of a cognitive model of processing animated diagrams.

2.4. Theoretical background

To achieve the aims of this thesis it is important that the focus of the research is on investigating the cognitive value of animation. Some previous research has investigated the cognitive value of graphical representations by identifying particular cognitive benefits of particular representational formats (e.g. Larkin and Simon 1987, Zhang and Norman 1994). When working with diagrams, learners need to focus on and collect various pieces of information, which need to be integrated both with previous (internal) knowledge and with the current (external) information they are using. The focus on a general level, in understanding the effects of different diagrammatic representations on comprehension, then, is the relationship between internal and external representations and the mapping of meaning across the two.

2.4.1. External cognition framework

As a theoretical basis for investigating the cognitive value of representations, the 'Cognitive Interactivity' framework developed by Scaife and Rogers (1996) emphasises this interplay between internal and external representations on cognition through; *(i)* exploring how new information is integrated with existing knowledge and re-represented and *(ii)* the identification of the cognitive benefits and costs of particular forms of representations, by identifying the properties of external representations in terms of their computational offloading. On a general level, computational offloading refers to the ways in which different structures constrain the amount of cognitive effort required to solve informationally equivalent problems. For example; graphical constraining occurs when different graphical forms of representations of the same information will limit the kind of inferences that are likely to be made, thus guiding thinking towards the concept to be acquired; Re-representation occurs when different external representations, that have the same abstract structure, make problem-solving easier or more difficult; Temporal/spatial constraining occurs when representations can make relevant aspects of processes and events more salient when distributed over time. In this framework, diagrams need to be investigated by examining particular aspects of learning such as, the kinds of inferences made, what information is lost, misinterpreted or correctly construed, how understanding is integrated with previous knowledge, and the effect of using different representations of the same structure.

On a more specific level, computational offloading may be a result of design issues or issues that relate specifically to the properties or features of the diagrams. In the field of computer systems and visual programming languages Green (e.g. 1989, 1991) introduced, and others have also developed (e.g. Green and Blackwell 1998), an analytical framework for evaluating the effectiveness of particular programming languages, enabling definitions of when particular visual programming languages or aspects of those programming languages, are beneficial or not for particular tasks.

2.4.2. Cognitive Dimensions framework

This framework focuses on analysing the semantic properties of diagrams in order to reveal particular cognitive benefits of particular diagrammatic representations for particular contexts. These properties are termed 'cognitive dimensions of notation'. According to Green (1989) "…. a 'cognitive dimension' of a notation is a characteristic of the way that information is structured and represented, one that is shared by many notations of different types and, by its interaction with the human cognitive architecture, has a strong influence on how people use the notation" (p.448). Here there is an emphasis on the interaction between the representation and human cognition, and the resultant effect on processing. The use of term 'dimension' within Green's (1989, 1991) framework means that certain features of a system or programme in relation to the user can be identified. These features exist on some kind of continuum that is likely to have trade offs in terms of benefits or disadvantages, for example, more of the identified dimension may give benefits to the system but not provide cognitive benefits, or vice versa. A system will also contain several dimensions, so that any changes on one dimension may also affect another dimension. This may have implications for design, such that if difficulties that arise from one dimension are resolved, the action taken to fix the problem may have adverse effects on another dimension (Blackwell et. al 2001).

Although Green (1989) cites several cognitive dimensions of notation and of information artefacts (and further research is expanding this list, e.g. Green and Petre 1996), and the context of their description has been applied to systems and program language evaluation as well as a wide range of artefacts (such as, central heating timers, telephones) some of these dimensions also emerge as potential starting points for investigating the cognitive value of using animation. For example, the concept of role expressiveness is defined as "the purpose of a component (or an action or a symbol) is readily inferred" (Green and Blackwell 1998, p. 41). This particular dimension refers to the visibility and parsability of a meaningful structure, defining the ease with which the structure can be, for example, broken into smaller parts, relationships identified. In terms of animation this may be translated into the visibility of particular aspects of an animated representation and to the parsability of the animated information. Thus, this might refer to which aspects of the animated diagram are most visible, and how easy or difficult it is for the learner to break down, or parse, all the pieces of information imparted into salient groupings and into a salient order, and make appropriate relationships or links between the information.

2.4.3. Relevant research for exploring cognitive interaction

As previously discussed research investigating the use of static and animated representations shows no conclusive understanding about the cognitive effectiveness of animation. However some research has begun to determine certain cognitive complexities of processing dynamic illustration (e.g. Kaiser et. al. 1992, Large et. al. 1994, Stenning 1998). Overall this research suggests that although animation may have potential benefits in the explicit depiction of dynamics, the increased processing demands of animation may be problematic for comprehension for several reasons: *(i)* the use of animation on diagrams results in an unmanageable possible increase of perceptually available information, especially where multidimensional dynamics are involved (e.g. Kaiser et al 1992, Lowe 1999); *(ii)* due to the transient form of information animation can result in increased memory load, the learner having to remember and integrate information across several representations (e.g. Kaiser et. al. 1992, Stenning 1998, Lowe 1999); *(iii)* the need to focus on several different changes occurring at the same time on the diagram, *(iv)* multimedia generally can create problems in learners having to integrate multiple representations not always simultaneously available on the screen (Rogers and Scaife 1997, Hoogeveen 1997). This section of the chapter will discuss research that has begun to identify features of animated representations that are important for cognition. For the purposes of this research three main bodies of work have been identified; complexities of animation from its fundamental form (Stenning 1998); the feature of graphical change (Lowe 1999); and the issues of multiple representations (Rogers and Scaife 1997, Cox and Brna 1995).

(i) Animation complexity

Certain aspects of animation have been cited to be potentially cognitively complex. Stenning (1998) suggests that such complexity may be a result of the particular characteristics of the medium. Firstly animation is evanescent, i.e. the information is transient and passes by as the animation plays. It is not persistent like that of a static diagram where the information displayed is continuously available to the learner. The evanescent form has certain cognitive consequences for the learner; *(i)* it increases memory load, as all sequences of movement displayed need to be held in memory in order to integrate new pieces of information with information that has already passed by, and *(ii)* the level of learner control is reduced, as the evanescent form means that learners are unable to reaccess pieces of information that are no longer perceptually available. Learners also have no control over what information is viewed, or for how long, as the information is continuously passing by. Although it is possible for some level of control to be given to the learner, allowing some re-access to information, for example, animations could run at slower speeds, they could be stopped and started by the learner, the underlying form of dynamic depiction remains a series of fleeting images resulting in transient information. Stenning (1998) also discusses the implications of the expressiveness of animation. He believes that animation demands that all fields displayed are fully determined at all times. This means that all aspects of a process or system occurring at a particular time must be shown simultaneously. If only one part of a dynamic process or system is depicted the learner could make false inferences about the way that the system or process works. However, the trade off is that this may make focusing attention on particular aspects of the representation problematic, which consequently affects the expressiveness of the representation.

(ii) Graphical change

The transient form of animation results from the display of a sequence of still images the purpose of which is to depict change of some kind. This change is depicted through graphical differences from one frame to the next. Lowe (1999) has defined dynamics by specifying distinctive aspects of graphical change. Thus, graphical change can be described according to form or position, defined as extrinsic characteristics (movement from one location to another) or intrinsic characteristics (change in size, shape, orientation etc..) (Lowe 1999). By analysing these changes Lowe (1999) was able to show that there were differences in the level of attention or processing that occurred according to the type of graphical change. For example, information was extracted according to the 'perceptual conspicuity' of the graphical change taking place, i.e. if an item was moving from one place to another, this trajectory was attended to more than changes in the form, or the intrinsic characteristics of graphical changes taking place. This means that the kind of information that is extracted from an animation is likely to be fragmented and consequently incoherent. However, the primary attribute that animation offers is this explicit depiction of changes over time. Further research into the cognitive effects of these different forms of graphical change, not only in terms of their perceptual prominence, but also in terms of their interpretations, would be beneficial in informing about the way that information is processed from animation.

(iii) multiple representations

A further issue that emerges from analysis of the representational form of animation is the resultant number of different frames required to depict changes over time. Each frame that depicts the process or system is in some respects different from the previous frame, although there will also be continuous underlying similarities. Taken together this results in a series of multiple representations, requiring integration from one representation to another on the half of the learner. Not only is the learner having to integrate information from different representations, but also from representations no longer available on the screen. Integration across representations not simultaneously available has already been cited to make understanding more problematic (Hoogeveen 1997, Rogers and Scaife 1997). The majority of research exploring the effects of multiple representations investigates integration or understanding from more than one different representational format rather than from several instances of one representational format, as is the case with animation. For example, one aim of research is to examine how different combinations of representations influence learning (Ainsworth 1999), under the premise that learning benefits can be obtained from the particular properties of each representational format to facilitate more comprehensive understanding (Van Labeke 2001). In some respects animation may be assumed to offer the same kind of benefits in that it provides 'more' information to the learner, in the case of animation it offers more dynamic information. However, a major difference is that learners using animation are required to integrate constantly changing information at the same time as they are viewing new information.

Other research has investigated the use of multiple diagrams in diagrammatic reasoning, and has cited additional cognitive burdens for learners who are required to, *(i)* remember where to look next in the total set of diagrams, *(i)* extract information across the multiple diagrams, and *(iii)* integrate the extracted information to build up a coherent representation (Kim and Hahn 1997). However, here the set of diagrams together make up a 'whole' diagram, and therefore again differ from animation where the multiple diagrams portray a whole process rather than smaller parts of one diagram, they display smaller parts of a process. Kim and Hahn (1997) suggest that facilitation of integration occurs through provision of visual cues that indicate relationships between items in one diagram and items in the other diagrams, and link the information inferred from different diagrams.

Despite these differences in characterization of multiple representations or multiple diagrams and a composite series of diagrams produced by animation, there are parallels between the kinds of activities learners are having to undertake, namely making links between events or items on diagrams, and integrating the information across the different representations.

2.5. Cognitive models of processing

Much research in understanding different aspects of cognition has explored ways in which information is processed in order to describe a cognitive model of processing for a given area of cognition, for example, models of memory (e.g. Tulving 1972, Craik and Lockhart 1972), models of reading (e.g. de Beaugrande 1985), models of problem solving (e.g. Simon 1985), models of representation or mental models (Johnson-Laird 1985). The literature on cognitive modelling is wide, therefore for the purposes of this thesis the concept of cognitive process models will be discussed in ways specifically related to providing a foundation for this thesis to explore ways in which information is processed from animated diagrams. Although, there are many different ways that a process model can be conceived some particular classifications can be identified relating to the representation, the learner and an interaction between the two.

2.5.1. Top-down and bottom-up processing

One conception is that a cognitive model consists of two highly interrelated processes where the characteristics of the representation interact with the characteristics of the learner. This model consists of the perceptual process and the conceptual process, or in other words, bottom-up and top-down processing. Perceptual or bottom-up processing emphasizes the external representation, where understanding begins with processing small units from the representation and proceeds from part to whole understanding. In learning from diagrams this would entail cognitively accessing the visual components of the diagram, and in animation this would also include the dynamic events that occur. Conceptual or top-down processing emphasizes what the learner brings to the representation, such as prior knowledge and experience that enables the generating and refining of hypotheses. Thus, understanding proceeds from whole to part with prior knowledge guiding the learner to more specific information. In learning with animated diagrams the extent of prior knowledge and expertise at reading diagrams would cognitively guide the learner in their processing of the information. Previous research has confirmed that significant differences exist in the way that representations and external tools to cognition are used according to these differences:

(i) Level of prior knowledge

The fundamental differences between novice and expert are the size of their domain knowledge (larger) and the way that knowledge is organised (better) (Satchwell 1996). Research has shown that there are differences in the way information is perceived and understood according to the level of expertise of the learner/user, due to the effect of their internal representations on the way they interact with the diagram. This phenomena has been demonstrated in several different domains and contexts. An early study carried out by De Groot (1965) showed that expert chess players used information from a chess display significantly differently from novice chess players. Experts not only recognised more meaningful chess configurations, but organised the information into chunks that related to specific functions or strategies. Chunking meaningful information also facilitated their memory of what they saw. Similar results have been found in mathematics (Hinsley et. al 1977), electronics (Egan and Schwartz 1979), computer programming (Ehrlich and Soloway 1984) (cited National Research Council 2000).

Cognitive processing of dynamics has also been shown to differ according to the level of domain knowledge (Lowe 1994, 1999). Lowe's (1994) study investigating differences between novice and experts of meteorology using animated representations of weather maps, showed that those with low domain knowledge tended to rely on the visuo-spatial characteristics of the diagram to drive their interaction, rather than on domain relevant descriptions and relational aspects of meteorology, which significantly affected the kinds of predictions made. Experts, therefore, perceive a diagrammatic representation in a more meaningful way (relating to the task, goals or aims of the information, and the wider context of the domain), are able to reduce processing/memory load by chunking information appropriately, structure the information they perceive in a more relevant way, and use the information to make more appropriate deductions, inferences or predictions.

(ii) expertise with the representation

Type of processing can also be different according to expertise at using the particular representation. According to cognitive load theory automated schemas of representations facilitates processing, for example, an expert in algebra will treat the equations as a single automated schema or 'chunk' requiring less working memory, whereas a novice needs to treat each symbol individually increasing working memory (Tuovinen 1997). Those with more expertise at reading diagrams (or particular types of diagrams) will more likely process information from the diagram more efficiently, and therefore differently, than novices to diagram reading.

2.5.2. Structure versus function processing

A model of processing that focuses more on the representational characteristics can be divided into two aspects: understanding the structure of the concept and understanding the function of the concept. In the context of diagrams this would entail understanding the structure through identifying and understanding the components of the diagram as well as understanding the function of those structures within the diagram. These aspects can be further conceived on a general level and a specific level in terms of processing. At a general level of processing the animation understanding the structure entails integrating the static components of the diagram with the dynamic components, and understanding the functional relationships between the two. On a more specific level a model could be described for particularly processing the dynamics i.e. for processing graphical change. Here understanding can again be divided into structure and function, the structure comprises the graphical changes themselves and the function comprises the function or meaning of those changes. The research in this thesis concerns both the structural as well as the functional understanding of animation.

2.5.3. Incremental reasoning and cognitive models

A model of processing that focuses on the learner aspects of processing includes models of incremental reasoning. Incremental reasoning, when learners gradually build up their knowledge by taking in small amounts of information at a time, gradually combining their knowledge with previously acquired pieces of information, has been found to take place during reasoning about dynamic information from static diagrams (e.g. Hegarty 1992, Narayanan, Suwa, & Motoda, 1994) and learning from animated diagrams (Jones and Scaife 1999). From their research into models of mental animation through multimodel learning (learning with multimodal representations i.e. multimedia systems) Narayanan and Hegarty (2000) propose a cognitive model for understanding multimedia presentations in the domains of mechanics and algorithms. These domains consist of the use of dynamic or changing information. In order to learn within these domains Narayanan and Hegarty (2000) propose the following cognitive stages: decomposing graphical representations into smaller components: making connections in memory between components, both between each other and to prior knowledge: making referential connections between different media type displays that refer to the same domain: identifying causality within the system: constructing a dynamic mental model by mental animation. Although, mental simulation was the underlying basis of this research, some aspects of this kind of cognitive model may be necessary for comprehension using animated diagrams, for example, decomposing graphical representations into smaller components (for working with animation this comprises decomposition on two levels, perceptual aspects i.e. graphical change and conceptual aspects i.e. domain sections): making connections in memory between components, both with prior knowledge and with each other in both graphical change and domain sections: as well as identifying causal links. The concept of decomposing information into smaller components has been proposed to underlie many processes of perception, learning and cognition (e.g. De Groot and Miller, cited Gobet et. al. 2001). In their research Gobet et. al. (2001) distinguish two forms of chunking; the first is deliberate, goal-oriented chunking, the second is automatic chunking which is linked to perceptual processes. This theory of chunking corresponds to top down and bottom up processing and to the notion of the ways in which an animated diagram may be decomposed or parsed into smaller components for processing.

This section introduced some aspects of cognitive models for the research in this thesis, showing the importance of the representational features, the learner features and the interaction between the two in the processing of information. Propositions from these kinds of models form the basis for research in this thesis investigating cognitive processing of animated diagrams, the particulars of which are explained in more detail in chapter three.

2.6. Summary and conclusion

This chapter has placed the current research within the field of external representations and cognition, and has reviewed research that has focused on animation as an external tool in the light of the proposed research in this thesis. The review also described relevant theoretical and analytical frameworks as a basis for the subsequent research in this thesis, as well as introducing the concept of processing models in the context of defining a cognitive model of animation. There are several other factors and variables which may also affect the cognitive effectiveness of animation, but are not explored in this thesis. The problem at present is that the different factors and variables are so numerous that the characteristics of animation are difficult to expose. What is needed first is a standard model of processing that can be applied in future research to uncover the specific effects of particular other variables. However, some important variables that warrant further investigation are presented in the final chapter of this thesis (chapter nine) in the light of both relevant previous research and the findings from this current research.

Chapter 3

Theoretical Rationale and Methodology

3.1. Introduction

Chapter two presented a review of relevant background literature to this research. This chapter explicates more specifically the problem space addressed in this thesis and the ways in which the problem will be tackled. The focus of this thesis is to investigate ways in which learners cognitively interact with animated diagrams to learn about dynamic processes, with a view to describing components that may contribute to a cognitive model of processing animation. To do this the research focuses on investigating the effects of some of the properties particular to animated representations on understanding and learning. This chapter will, therefore, describe the rationale and method for the subsequent studies in this thesis in the following sections *(i)* defining the problem space, *(ii)* identifying particular properties of animated representations, *(iii)* identifying learning steps potentially required with this kind of representation, *(iv)* proposing a cognitive model of processing, and *(v)* developing appropriate methods for researching this problem space.

3.2. Defining the problem space

As can be seen from chapter two research into the use of diagrammatic animation shows mixed results in terms of the learning or understanding that has taken place. However, research has not as yet uncovered the way in which learners read and integrate information from a dynamic representation. The present research aims to investigate more specifically the cognitive processing that occurs when cognitively interacting with an animated diagram, with the ultimate aim of describing a cognitive model of processing. This kind of investigation should show more precisely how particular aspects of the representation influence the way learners perceive information and construct knowledge. Constructing a process model should potentially mean that conclusions drawn about cognitive processing with animation are more generalisable across different kinds of animated diagrams, as the basis used here for the research defines animation in terms of its specific characteristics, rather than the characteristics of the subject domain itself. This may not only provide information for creating guidelines on designing effective representations, but also potentially enables the development of guidelines on how best to direct learning when using animated representations.

3.2.1. Defining a process model

From chapter two it is evident that cognitive process models are used in various domains in an attempt to describe cognition, and can be defined in different ways and at varying levels of description. Using animated diagrams involves 'reading' a particular kind of representation. The theoretical rationale in this thesis emphasises the contribution of both the learning requirements and the representation in facilitating cognition. This is therefore in accord with an interactive process of 'reading'. For the purpose of this research a process model will be investigated at a level of description that focuses on the salience (visibility and identification) of animated features and the interpretation of that animated information, together with the integration of the information acquired, and the potential effect of these on resulting conceptual understanding.

To do this certain principal issues need to be addressed and defined in relation to the research. *(i)* Identification of the specific properties of animated representations. This distinguishes the relevant features of the representation to be investigated, such as, graphical change, which should provide information specific to a cognitive model of animation. *(ii)* Identification of the learning steps required to understand information from animation, for example, identifying important components of the diagram for acquiring relevant information, identifying graphical change and understanding graphical change. Defining these issues in detail will then facilitate the appropriate design of empirical work. A process model of animated diagrams proposed by this research should, therefore, explicate the cognitive processes involved in using this representational format in terms of its particular representational properties and in terms of the learning steps required. This should provide information about how specific properties of animation may affect cognition, the kinds of understanding that may take place, and aspects of the representation that are pertinent in facilitating or hindering comprehension.

3.3. Identification of specific dimensions of animated representations

3.3.1. Properties of representations

Research from static diagrams as well as sentential representations, suggests that each representation has certain properties that are inherent in the structure of the representation that may be beneficial (or not) to cognitive processing in domains such as problem solving or reasoning. Properties of static diagrams already identified will inevitably also be present in animated diagrams. However, it is not only the properties, but also the cognitive effects of the properties that are important for this research. In order to investigate the underlying cognition of using animation, the importance of identifying aspects of a representation that affect cognitive processing of information has been cited by Green (1989, 1991) and Scaife and Rogers (1996). As described in chapter two, the 'Cognitive Interactivity' framework (Scaife and Rogers 1996) highlights the importance of investigating external representations in terms of the cognitive interaction between internal and external representations by exploring ways in which new information is integrated with existing knowledge and identifying particular cognitive benefits and costs of representations by describing properties of the external representation in terms of their computational offloading. On a general level, computational offloading refers to the ways in which different forms of the representation can confine the amount of cognitive effort needed to solve problems or understand concepts from the representation. On a more specific level, computational offloading may be a result of issues that relate specifically to the graphical properties of the diagrams, for example, graphical constraining, temporal and spatial constraining, and other properties of the external representation that are related to design issues, such as, explicitness, visibility - the degree to which learners attention is directed to important aspects at different stages of the learning task (see 2.3.1. for more detail). Green (1989, 1991) has proposed the importance of analysing the semantic properties of diagrams, in order to discover the cognitive benefits of particular diagrammatic semantics for particular contexts (see 2.3.2. for more detail), which he termed cognitive dimensions. Similarly, animated diagrams may have specific properties that facilitate or hinder the cognition process. Therefore, an effective paradigm for investigating animation, is to define the form of animation and identify cognitive and/or semantic properties or dimensions that are specific to animation, and explore ways in which they are beneficial or detrimental to processing information.

3.3.2. Cognitive Dimensions

As presented in chapter two the term ‘cognitive dimensions’ (Green 1989, 1991) was developed in the context of analysing systems and programming and a wide range of information artefacts. Certain features of a system, identified in relation to the user are characterized as cognitive dimensions because they have some relevance to the system or programme being cognitively beneficial or hindering. In understanding cognition in relation to animation identifying some kind of dimensions of the diagrams that have a cognitive effect (be it beneficial or detrimental to learning) may help us to understand how the representation guides or influences reasoning or learning with that particular representation. In this way the concept of cognitive dimensions may be a useful way of investigating the effects of animation on cognition. If features or properties particular to the representation can be identified, then these aspects can be investigated in terms of their effect on cognition. These features or properties of the representations may then be able to be modified by designers or learners, therefore providing more or less of the feature that is beneficial or not to cognitive processing. These features too are likely to offer trade offs in terms of cognition, e.g. by providing one aspect that is beneficial to cognition may affect another dimension that is then detrimental to cognition. In the context of this thesis these features will collectively be termed ‘cognitive dimensions of animated representations’ or CDAR (akin to Green’s cognitive dimensions of notation).

3.3.3. Properties of animated diagrams

Animated diagrams are a special class of diagrams, therefore representational properties affecting cognition that are inherent in diagrams generally will inevitably be present in animated diagrams too. For example, the form of diagrams is generally abstract resulting in a limited amount of information being displayed. This ‘selectivity’ has been suggested to be cognitively beneficial for several reasons, such as, highlighting the main important aspects, enabling clarity through omission of unnecessary detail, comprising markings which indicate relational aspects, and a more specific focus of information results from removal of the topic from its broader context (Lowe 1994). Diagrams also provide explicit visual information about such aspects as spatial relations, and enable simultaneous presentation of large amounts of information, facilitating information search in one representation. However, although the static graphical illustration may be similar in both a static and animated diagram, the explicit depiction of movement through animation creates a fundamental difference between the two representations. This explicit depiction of dynamics also generates specific representational properties. These properties in turn may affect the way that the information is processed, and as such, can also be seen as Cognitive Dimensions of Animated Representations (CDAR). Certain dimensions relating to explicit depiction of dynamics are selected and used for investigation in this thesis.

3.3.4. The form of animation

Cognitive properties specific to animation result from the basic graphical form of animation itself. The Computer Animation Dictionary (Roncarrelli 1989) defines animation as "producing the illusion of movement in a film/video by photographing, or otherwise recording, a series of single frames, each showing incremental changes in the position of the subject images which when shown in sequence, at high speed, give the illusion of movement". Animation is, therefore, a sequence of fleeting images occurring in the same place but distributed across time. Generally this means that an event denoted by an earlier set of images occurs before an event denoted by a later set of images (Stenning 1998). Animation deals not only with movement from one location to another, but also with any change in an object be it change in position, colour, brightness, size, and metamorphosis, i.e. change from one object into another (Sundberg 1998).

3.3.5. Preliminary Cognitive Dimensions of Animated Representations

Previous research has already identified some specific properties of animation that affect cognition (e.g. Lowe 1996, Stenning 1998). The overriding quality that animation appears to have is that of visual explicit depiction of dynamics (visual dynamic explicitness). Although this might be cognitively beneficial due to the provision of clearer dynamic aspects of a process or system, and due to the degree of computational offloading this might offer, previous research has suggested that this visual explicitness of dynamics may also bring with it other cognitive effects. The CDAR identified for this research are as follows:

(i) Multidimensionality (amount of simultaneous information)

Diagrams are often used to display large amounts of information simultaneously in one representation. As a result of the explicit depiction of dynamics, animated diagrams have an additional amount of perceptually available information. This could influence cognition in two different ways: *(i)* reducing computational offloading through visual explicit depiction of dynamics making motional aspects of the information more salient and 'easy' to understand, and /or *(ii)* increasing the effort required on the part of the learner to focus their attention as a consequence of the large amount of different information occurring in the diagram at one time. The quantity of information may not only be due to increased perceptual availability of dynamics, but also to the desire or need to ensure that the animation does not generate false inferences due to abstracting information. Stenning (1998) argues that “animation demands that the whole field is fully determined at all times”, i.e. that the animation illustrates all aspects of the depicted context at all times. Thus, if certain dynamics isolated from their context are depicted the learner may falsely infer that those dynamic events not concurrently shown are no longer taking place or do not occur simultaneously. ‘Fully determined animation’ could arguably increase the difficulty for the user to focus their attention on any one particular aspect, or even to know which are the salient aspects to attend to. This may create additional complexity to the information being displayed in terms of the level of dynamic information load. Focusing attention on the important features of a visual representation, including animation, has already been stipulated as important for learners (e.g. Rieber 1991, Milheim 1993).

(ii) Transient media

As cited above the form of animation differs most from static in that the illusion of movement is brought about by depicting a series of consecutive frames. This intrinsic property of animation representing change over time means that the media fundamentally differs from that of static presentations in that it becomes evanescent, as opposed to persistent (Stenning 1998). Thus, information is transient, it passes by and is no longer available for perusal by the user. Its evanescent quality, therefore, *(i)* contributes to memory load, as the learner has to remember what has previously happened in order to link it with what is now happening, and *(ii)* affects the ease at which a learner can re-access the information. Learner/ user control is further reduced by the fact that the changes that constitute evanescence are traditionally with the creator of the animation, and not with the learner or the learners needs. However, it is true that only some of the information (i.e. dynamic information) on the diagram is transient, while some underlying depictions of a system remain persistent. It is also true that animated diagrams may not be uniform in the degree to which they are animated, for example, only a proportion of the aspects of the diagram that could illustrate motion may be animated. This in itself may have implications for cognition as the learner is required to integrate information that is animated with information that is static.

(iii) Graphical change

Another inherent property of the animation is that the sequence of still images depicts change of some kind, enabling visually explicit depiction of dynamics. Lowe (1999) identified aspects of dynamism in relation to change according to form or position, defined as extrinsic characteristics or translation to refer to movement from one location to another, and intrinsic characteristics or transformation to refer to change in size, shape, orientation etc... These changes are physical, morphological changes in the sense that they refer to the surface details of graphical components and can be perceived directly through vision. These can be seen as 'morphological properties' of graphical change. However, these changes also "represent" something in the sense that they denote some kind of event or meaning within the domain being animated. If the graphical change is to make any sense in terms of what it is representing, then the learner needs to distinguish particular meaning of each graphical change. The meaning of the graphical change can be seen as 'semantic properties' of the animation. Therefore, animation properties relevant to the learner are morphological properties in terms of their salience, and semantic properties in terms of their interpretability. Lowe (1999) also suggested that learner attention is selectively distributed according to perceptual salience rather than thematic relevance. This results in "selective inattention" which occurs according to the relative magnitude of changes and their extrinsic or intrinsic nature. Therefore salience of graphical change may be dependent not only on the graphical component itself, but also on the frequency, speed, and magnitude of dynamic change.

(iv) Explicit temporal depiction

As animation form inherently depicts a series of changes through sequences of still images, it inevitably depicts an order of events within the representation. However, not only does it display temporal sequence, but it can also show tempo. Thus, explicit depiction of any differences in relational rate of change or motion are displayed. Although this feature is important in the use of animation it is not specifically addressed in this research, as several aspects of temporal depiction, such as, relational timing of events, the effect of different speeds or tempo, require investigation. Instead these issues will be discussed in more detail in recommendations for future research.

Thus, animation has dimensions specific to its representational format that may influence cognition. This thesis concentrates on the following properties of animation together with their associated cognitive demands; *(i)* multidimensionality, which here refers to the quantity of simultaneous information, which may affect the level of computational offloading and appropriate attention focus, according to the level of dynamic information load *(ii)* the evanescent quality of the presentation, which contributes to memory load, and *(iii)* the graphical change used to depict dynamics, which the learner must identify and interpret, and therefore has at least two cognitive demands; visibility demands and interpretive demands. Thus, out of these representational properties it can be seen that they have implications for cognition in terms of the visibility of the information (this is akin to Green's 1989 cognitive dimension of role-expressiveness, see 2.3.2.), attention focus, and memory load.

3.4. Identification of learning aspects

Identifying the learning process can be approached in different ways, for example by doing longitudinal studies with novices learning to be experts in a particular domain and discovering the stages or strategies used in moving from novice to expert (Anzai 1991). Other research emphasises the importance of identifying particular characteristics that are thought to promote learning, such as student prior knowledge, skills, learning preferences (Brna, Cox and Good 1997). According to Green (1989) the use of cognitive dimensions should be tied to a clear model of user activity, and given this particular model of behaviour analysis using cognitive dimensions can inform about the requirements of the system. In this research the model of user activity is learning dynamic systems using animated representations, where the style of interaction with the animation is primarily cognitive. Although the focus of this research is primarily on cognitive interaction with animated diagrams it is understood that a user activity model where the user has different levels of physical interactivity with the representations (e.g. by varying types and degrees of manipulation) may bring to light different cognitive dimensions of the representation. Green (1991) also expresses the need to understand the users' 'model' or knowledge structure in order to understand the visibility and parsability of a meaningful structure. This may be interpreted as the visibility of particular aspects of the representation and as the parsability of the components within the information. In terms of an animated diagram this might refer to which aspects are most visible, and how easy or difficult it is for the learner to parse all the pieces of information imparted into salient groupings and into a salient order. This suggests the importance of understanding a learners 'mental model' of a system in order to facilitate parsing of information or in order to make visible salient aspects of information. Therefore understanding the learning process and learner task are important in identifying cognitive processes for describing a process model.

There are many aspects of the diagram that ultimately contribute to making sense of the information, several of which are true of diagrams generally. For example; context related issues, such as, being aware of the subject domain of the diagram, being aware of the frame of reference, knowing specific aspects within that subject domain that need to be learned; graphical component issues, such as, mapping of components, relationships between components, and dependencies between components. There are other aspects such as particular design issues that may influence the readability of the diagram. For example, there are several different ways of graphically depicting the concepts displayed, as well as different ways of graphically illustrating motion. For instance, flow may be depicted using arrows showing direction, dots as fluid, solid use of colour filling the track of the flow etc.. However, this thesis will not address the effects of design at this level (e.g. the effect of colour or size of a particular graphical object), but will attempt to look at design issues on a more global level such as the degree of dynamic information, the visibility of dynamics and the kind of interpretation of dynamics. There are also further aspects of the diagram that contribute to understanding; *(i)* the moving aspects of the diagram; movements of parts remaining in one location; movement of parts from one location to another, which parts move, how the parts move, why the parts move, what function they serve, the dependencies of one movement on another, what moves from where to where, the functions that the movements serve, the changes that take place *(ii)* the mapping of animated components to the real world, to one another and relationships between dynamic and non-dynamic information *(iii)* temporal relations: what moves where when, any order of changes or events, the speed of the different movements and/or components, time delays between movements of parts or movements from one place to another.

3.4.1. Identification of appropriate learning process

The research here uses a model of learning that focuses on aspects within the representation that are important for contributing to the learners understanding of the depicted process. In order to make sense of an animated diagram, there are several tasks required by the learner. Once the overall domain and frame of reference of the diagram have been established, the learner needs to identify components of the diagram. By selecting pieces of information the learner is automatically segregating information in the representation. Therefore, the next stage of processing involves reintegrating segregated pieces of information into a coherent whole. However, at some stage in these proceedings the learner has to attribute meaning to each of these aspects in order to understand both the segregated pieces of information and the integrated pieces of information. The meaning placed on separate pieces of information will inevitably influence final understanding of the representation as a whole. Therefore, not only are the integration of perceptual and conceptual processes important in diagram understanding, but also the process of interpretation. The emphasis in this thesis is on the learning process occurring in relation to the CDAR (Cognitive Dimensions of Animated Representation) described above.

Much emphasis is put on parsing as an important element in using external representations to facilitate knowledge construction (e.g. Witrock 1977, Laurillard 1995). The concept of parsing although traditionally used in the domain of language understanding can be applied to other information distributors and may be a useful concept to use in determining valuable features for reading animated diagrams, providing a basis on which to analyse how animated information is perceived, attended to, interpreted and understood. Parsing in reference to language means to break down a sentence into component parts of speech (into words or phrases) and identify each component for analysis (e.g. adjective, verb, noun). Parsing in linguistics can also be divided into *lexical analysis* which focuses on the form, function and syntactical relationship within a sentence, and *semantic parsing* where the meaning of the string of words is determined (http://www.webopedia.com). In language semantic parsing can be based on several aspects, for example, interpretation can be based on intonation, meaning within the context, punctuation, and /or listeners input/interpretation. Here information is broken down into meaningful parts, possibly in different ways and for different reasons in order to understand the meaning intended. Diagrams also distribute information, research having shown that they too are parsed in order to understand the information being imparted. Diagrams also can be parsed syntactically (where the focus is on the graphical structure and relationships in the diagram, e.g. Futrelle 1998), akin to lexical analysis, or semantically (where the focus is on the meaning being imparted in the diagram) akin to semantic parsing. Rieber (1990) cites the importance in chunking information into relevant components in focusing attention and directing awareness to relevant motion taking place.

The research in this thesis is interested in the *semantic parsing* of animated diagrams and refers to the cognitive parsing of visual information. As a particular feature of animation is to explicitly depict movement, parsing of the dynamics themselves may be an important part of comprehending the animation. However, in order to comprehensively understand a concept it may also be important to make links between pieces of information and integrate that information into a coherent whole. Parsing by isolating smaller sections of the diagram or information as a whole (not just dynamics) may also been seen as being instrumental in learning with animation. Thus, there seem to be two plausible levels in parsing an animation to extract meaning from the diagram. In this thesis parsing will be defined on two levels *(i)* parsing in terms of dynamics (graphical change), and *(ii)* parsing of the information of the domain itself.

(i) Dynamic parsing

This comprises parsing dynamic information from the diagram i.e. change of some kind from one frame of the animation to the next. These changes may be in terms of dynamic form and /or graphical change and the interpretation of these. Dynamic form includes the following aspects; type of movement, rate of movement, frequency of movement, location of movement, and size of the moving object/aspect. Graphical change consists of change of position (translation) and change of state (transformation) (Lowe 1996). These changes need to be identified, separated, grouped with other information, interpreted and incorporated with each other in order to build up knowledge of the depicted concept as a whole. Each of these aspects will be identified and discussed below.

(ii) Domain parsing

This comprises parsing of relevant sections within the domain before integrating these pieces of information together. As well as parsing dynamic aspects specifically, the diagram can also be parsed on the level of small discrete subsections of information. This facilitates focus of attention onto important domain aspects of the diagram and may enable guidance in building up a ‘holistic’ picture.

The parsing process as described here focuses on the procedure as one of decomposition of the representation consisting of the following stages *(i)* selection of information and *(ii)* segregation of information, but does not include what seems to be a vital part of understanding - that of interpretation of the components of information, be they dynamic or domain aspects. Placing meaning or interpretation on particular pieces of information may be critical to the overall understanding obtained from the diagram. Therefore, when using animated diagrams parsing can occur on a graphical change level and a general domain level, both of which comprise a perceptual stage, an interpretation stage, and an integration (conceptual) stage. Thus, several relevant stages of the parsing process that may contribute to a comprehensive understanding from an animated representation are proposed.

(a) selection and identification of information

To make sense of any graphical representation, the components of the diagram must be noticed and, in turn, recognised and mapped onto objects or concepts from the real world. In animated diagrams not only must these components be recognised as representing things from the real world, but any dynamics between components or changes of components must also be noticed and seen to represent events that occur within the real world. The question is whether or not certain dynamics draw more attention (are more noticeable) than others, which components or events are most salient and why. Selection of information is concerned with salience and mapping of motional aspects of the diagram.

(b) Segregation of perceptual dynamic information

By selecting certain pieces of information, graphical objects or movement, the representation is automatically being segmented or broken into smaller components. According to literature on vision, perceptual parsing consists of visual segregation. Visual segregation encompasses: separation of an object from its surroundings by identifying each component object as a whole: and perceptual grouping, which refers to the way objects are perceptually grouped. This grouping can significantly effect the perceived image, and potentially the interpretation of that image. So, in animated diagrams is there any basis for segregation and perceptual grouping? What criteria are used for segregating dynamics? e.g. type of movement, location of movement. Are the different categories of dynamics (dynamic form and graphical change of state) segregated and grouped separately.

(c) Interpretation

This comprises putting meaning onto graphical change and dynamic form in order to make sense of the dynamics displayed in the context of the domain of the diagram. Interpretation could be seen to take place on two levels, *(i)* mapping the graphical object onto something it is representing in the real world, and *(ii)* interpreting the meaning of any graphical change that takes place. It is the latter of these that is the primary focus in terms of interpretation in this research, as ‘reading’ animated diagrams requires the learner to understand the meaning of the dynamics displayed.

(d) Information integration

This comprises integrating the pieces of information taken from the diagram, and from previous knowledge to make sense of the system. Integrating the information from the diagram consists of at least two aspects, *(i)* ordering the separate pieces of information, and *(ii)* making links between separate pieces of information. Ordering information refers not only to the order when reconstructing information, but also the order in which focusing and attending takes place, and the order in which information is sequenced while interacting with the diagram. These aspects may all affect the meaning and understanding taken from the diagram. Making links refers to the relevant connections that learners make between various aspects of the information. Integration of information when using animation may be complicated by certain properties of the representational format. For example, the animation is constructed of many different frames depicting change. This not only renders the information transient, but also creates multiple representations, across which new information cannot be compared with previous information due to its transience.

3.4.2. Summary of proposed learning process

Individual differences in the amount and type of previous knowledge are inevitable, and information cannot be tailored to all of these individual differences. The task of the learner in a given learning context may also differ, as well as the animations themselves. The level of interactivity and control available to the learner, and the degree to which these activities can be customised to individuals may also differ. Although this kind of design may have different cognitive effects than animating alone, the present research concentrates on the cognitive effects of straight play through non-interactive animation. Despite this the important aspects of learning must still be to be able to focus on salient pieces of information, understand the pieces of information and integrate this information to construct relevant mental models. On one plane, therefore, cognitive processing of animated diagrams can be seen on four principal levels: a visual graphical level, an interpreting level, an integration level, and a conceptual level. These principle levels can be explained in the following way:

(i) Visual level, which requires a learner to perceive components of the diagram and different graphical changes that occur, and is therefore dependent on the salience of the components and their dynamics. This level will potentially be affected by the multidimensionality of the representation and the evanescence of the media.

(ii) Interpreting level, which requires that a learner make accurate interpretations of the diagram. This entails understanding the meaning not only of individual components in terms

of what they represent, but also the dynamic changes that occur to those components and what this means in relation to the diagram. The meanings in relation to each other also need to be understood (causality). This level will potentially be affected by the visual level of processing that is or has taken place.

(iii) Parsing, which requires that learners parse both the dynamic and domain information in order to make appropriate implications and inferences.

(iv) Integration, which requires the learner to integrate all the information together, making links between information on the diagram.

These levels are probably processed in parallel in some kind of hierarchical manner in terms of the above categories, with the surface level at the top level and interpretation at a deeper level. All of these processing stages or components may be influenced in some way by the properties or features of the representation itself (e.g. multidimensionality, graphical change, evanescence). Generally speaking it seems that there is likely to be some trade off between benefits and disadvantages of all aspects of the properties of the representation in terms of cognition. More perceptual information may provide computational offloading, but too much may result in complexity, creating difficulty in focus of attention etc..

The previous two sections have highlighted characteristics and inherent features of animation which may be considered to affect cognition when using animated diagrams, and has defined a learning process considered to be appropriate when using this kind of representation. Those characteristics or features of animated diagrams may facilitate or hinder this process of learning. Thus, this research will investigate how information is processed from an animated diagram by exploring how information is selected, segregated, interpreted, ordered, and finally how links between pieces of information are made, according to the currently defined CDAR of animation. In this way the manner in which certain features of animation affect cognitive processing and in what ways they facilitate or hinder learning can be explored. It is this interaction that will be used as the basis for defining the final CDAR for animation as explored in this thesis.

3.5. Proposed Cognitive Model

From the learning model proposed above and identified features of animated representations, the following initial cognitive model can be proposed. At one level of description processing can initially be seen to consist of four principle components:

(i) Visual graphical level which consists of processing the graphical components and the different graphical changes that occur on the animation, and is dependent on the salience of those components and their dynamics.

(ii) Interpretation level, which consists of understanding the meaning not only of individual components in terms of what they represent, but also of the dynamic changes that occur to those components and what this means in relation to the diagram as a whole.

(iii) Integration level, which consists of integrating those dynamic pieces of information together, making links between components, their dynamics and the persistent aspects of information on the diagram. This level should also include integrating the external information with current internal knowledge.

(iv) Conceptual level, which consists of understanding the system or process in such a way that inferences about cause and effect can be made, and higher level inferences about potential consequences of interruptions r breakdowns in the system or process.

It is expected that these levels are processed in an iterative kind of way. Although at the beginning of processing the order described above may have some credence, it is expected that subsequent processing will occur in parallel such that some dynamics are identified, interpreted and integrated before others, and that the level higher conceptual understanding is related to the amount of dynamic information that has been processed to this level.

However, it is anticipated that these proposed principle components of processing will be affected by features of the representation such as, explicit dynamic depiction increasing perceptual availability of information, sequential presentation of information as well as parallel presentation, transience of the information. These features may affect the salience of components an dynamics, memory load for information gone before and anticipation of information in the future, attention to all the different changes occurring, and require linear processing as well as parallel processing.

Generally speaking it seems that there will be some trade offs between benefits and disadvantages of all aspects of the properties of the representation in terms of cognition.

More perceptual information may provide computational offloading to some degree, but too much perceptual information may result in complexity of the representation, making focus of attention difficult, and have an effect on the salience of information.

3.6. Researching the process model: methodological considerations

The theoretical basis from which to research a process model of animation has been explicated, but in order to investigate a cognitive process model of animation several methodological considerations need to be addressed: *(i)* the highlighted properties of animation need to be defined in terms of their proposed effect on cognition, and these aspects investigated, *(ii)* the choice of diagram class and domain to use for investigation, *(iii)* the choice of participants for experimental exploration, *(iv)* the design of the materials to be used *(v)* a suitable methodology for extracting this kind of information needs to be devised, and *(vi)* appropriate tests for assessing learning outcomes need to designed.

3.6.1. Chosen class of diagrams

Research from previous studies looking at the use of animation, suggests that the nature of the domain space influences the kinds of, and extent to which, investigations about the benefits of animation can be made. As the aim of the study was to establish more clearly the cognitive processing of dynamics and the benefits or disadvantages of learning using animation, and the essence of animation is dynamics, it seemed appropriate to work with domains where movement and change are inherent in the model or system being depicted. Thus, diagrams that depict dynamic processes, such as the blood flow in the heart, lend themselves to this purpose. This thesis, therefore, used the domain of cardiac circulation and respiration processes to investigate the value of animation when learning a dynamic process. Although it may be possible to get real pictures of the heart beating or images of the inside of the heart, the most usual representations for learning this process are schematic. Schematic representations also have been found to be more conducive to learning than pictorial representations (Hegarty and Kozhevnikov 1999). The studies reported here used schematic diagrams of the heart for learning the principles of cardiac circulation.

3.6.2. Choice of participants

Participants in all studies ranged between the ages of 12 – 14 years. This particular age group were selected as the domain used and the kind of information to be tested was considered most suitable for this stage within the school curriculum, without pupils being too familiar (and therefore 'expert') with the domain. This research, therefore, primarily involves low level domain knowledge users, indicating that their processing may be predominantly visuo-spatially driven (Lowe 1994). Thus the theory behind the design and methodology of the studies is a focus on visuo-spatial aspects of processing, and how this information may be integrated or a mental model built. However, the diagrammatic form (in terms of selectivity) also means that for a low domain knowledge user much information may be missing that would enable them to make relevant relational connections between information on the diagram and between relevant information not explicit from the diagram. Thus, another focus is on which aspects are salient or explicit and the effectiveness or not of these features.

3.6.3. Designing the materials

The materials used were presented and designed with a primarily visual emphasis. The key rationale for this was to enable specific focus on understanding the form of animation itself and the effect of this on cognition, without confounding variables on learning such as verbally given information. This meant isolating the visual aspects of the diagram, by removing or not including verbal or textual information about the meanings of the diagram or the conceptual information imparted. Textual information accompanying the diagrams and explanations from the researcher gave information only on the context and frame of reference of the diagram.

- Diagram context and frame of reference

When learning a dynamic process or how a system works with very little background knowledge, the knowledge construction process is likely to be distinctive. The representation and style of introduction to the domain will almost certainly affect the learning process. As the focus of this research is on animation properties, recognising the context or frame of reference of the diagram is not an important factor. For this reason the context and frame of reference was clearly given to the learners before they were introduced to the animation. This meant that the studies could be focused on the animation and movement aspects of the system, rather than on the leaner having to first work out the specific frame of reference of the diagram and the major components of the system .

- Learner task

Previous research that involves learning or knowledge acquisition suggests that learning is affected by the task the learner is required to undertake. The task will influence the kind of information attended to and the aspects of the information that are relevant to complete the required task. It is therefore important to ensure that the task set addresses the issues in the research question(s) being asked. It is also important to ensure that the task is appropriate to the participants, for example the kind of task given to secondary school students would be different from the kind of task given to university students. In this research the questions asked are concerned with the effectiveness or not of different external representations in cognition, but specifically in relation to animated (and static) diagrams of dynamic processes or systems. The tasks that were set, therefore, focused on aspects that relate to learning the dynamics of the system - areas of the system that could be depicted dynamically, such as learning about blood flow.

3.6.4. Methods

The methods used in the research need to produce data that can both generate descriptions of processing, as well as generate experimental evidence of patterns of processing. This necessitates the use of both qualitative and quantitative data. Qualitative data (e.g. verbal protocols) provides a rich source of description for proposed models of cognitive processing with animation, while quantitative data (using more rigid experimental conditions) provides experimental confirmation of proposed aspects of cognitive processing.

(i) Qualitative data

Verbal protocols and verbal description of the animations was the primary approach used. These were obtained through open ended interviews and co-operative working to encourage verbal interaction between both pupils and researcher. This method provides a richer kind of interaction with the information and richer source of data in terms of such, aspects as errors made, corrections given, and sudden realisation of knowledge. Therefore, despite potential disadvantages of this kind of approach (such as the need to facilitate interaction as participants may not be familiar or comfortable with talking, awareness of participants being selective about what they say due to inexperience at expressing their thoughts), this method was adopted as data was wanted, not only on the quantitative analysis of test scores, but also on the qualitative analysis of the kinds of information noticed and the ways in which pupils gleaned this information. Working in pairs also allows discourse between children, facilitating the collection of verbal protocols (e.g. Scaife and Rogers 1997, Johnson 1999, Schnotz & Grondziel 1999). One of the consequences of using verbal protocols is that pupils automatically embark on self explaining. As described in chapter 1 this can have significant cognitive benefits, and may affect learning outcomes of those pupils (Chi 1997). However, although this must be taken into consideration, self explaining still provides relevant information for this research.

(ii) Quantitative data

This kind of data provides more scientific evidence of the identified aspects of cognition taken from verbal protocols and descriptions, through the use of experimental manipulations and investigations of processing using animation. On the basis of descriptive evidence of processing controlled experiments were undertaken to compare learning and processing about different dynamic aspects of animations, also with the use of different animations.

Although there are a mixture of advantages and disadvantages to both methods of investigation, the joint use of qualitative and quantitative data enables a more scientific approach without losing the benefits of the richness obtained from verbal protocol data.

3.6.5. Assessing learning outcomes

Designing tests for assessing learning outcomes is a complex part of research. There are many different learning outcomes and many different ways of assessment. The outcomes of any test are dependent on many different factors such as the mode of assessment (written, verbal, diagram, computer or paper presentation) and the kind of learning (recognition or recall) being assessed, each of which comes with its advantages and disadvantages. Not only do modes of assessment differ, but also the kind of test possible with each mode, for example, a written test may be in multiple choice format or require a full descriptive paragraph. Naturally the design of the particular test within a certain mode will depend on the kind of learning being assessed, for example, multiple choice generates recognition whereas descriptive writing generates recall. Not only are outcomes affected by the above factors, but also by the kinds of information required - the specific content of the assessment - whether in written, verbal or diagram format, for example, factual, conceptual, or inferential. Thus, there are several design issues to consider when choosing ways of assessing learning. However, the outcome of the assessment will also be dependent on other issues, for example, the familiarity of the pupil with the kind of test being completed, as well the time expenditure required by the pupil, as some forms of assessment are more time consuming than others. These are important considerations given the constraints of carrying out research in institutional settings such as schools.

It is important, therefore, when designing assessments to first determine the kinds of learning required, the familiarity of tests as well as the specific learning outcomes to be measured. Each assessment format may provide different kinds of information about learning, therefore, this research makes use of a selection of these ways of measurement in an attempt to build a comprehensive picture of cognitive processing with animation. In this thesis each empirical chapter focuses on different learning aspects and assessment was therefore tailored to address the particular learning aspects involved.

The rationale for requiring learning outcomes also affects the approach of assessment. For example, comparison across different experimental conditions requires post testing, whereas an assessment of within subject learning also requires pre testing. Again pre and post tests and delayed post tests were employed according to the particular requirements of each study. When designing tests to assess learning various criteria must be taken into consideration, such as, the aims of experiment, the school curriculum, the age group concerned, varying pupil ability, pupil time limitations. Therefore for this research the aim was to establish the most appropriate tests for assessing knowledge for the following criteria;

- establishing levels of dynamic and static knowledge
- establishing levels of factual and conceptual knowledge
- appropriate for 12-14 year age group
- appropriate for the domain of cardiac circulation and respiration within the National Curriculum

However, some generality of design was employed across all studies.

(i) pre-tests

These were used where assessment of learning gains was specifically required. Some studies, for example, chapter 6 and 7, could not be pre-tested due to the content of the assessment. The pre-tests used were developed with the aim of providing a base line level of knowledge to compare with similar knowledge after experimental manipulation. To guard against the possibility of priming occurring from the pre-test, a split half technique was employed when pre tests were used.

(ii) post tests

The rationale of the post test will affect the specific content of the test, i.e. the 'questions' must be tailored to the information required, therefore different post tests were designed for the different studies undertaken. All testing was pilot tested to ensure that questions were valid, worded appropriately, not too difficult or too easy.

(iii) delayed post tests

The limitations of assessing cognitive benefits only with pre and immediate post tests are that further delays in testing may result in different conclusions (Large 1996). The use of delayed post tests, not only demonstrates the influence of learning experiences later (Scanlon et al 1998), but also allows conclusions to be drawn between the immediate and delayed effect of animation. Delayed post tests are, therefore, employed in a number of studies where learning gains are being evaluated (e.g. Thornton and Scoloff 1998, Sivasubramaniam 1999). However, although useful, the outcomes of delayed post tests are likely to be dependent on the time delay between testing. In this thesis delayed post tests were used in the final study as this study targeted more overall understanding of the depicted concept rather than graphical salience covered in earlier studies.

(iv) Representational format of tests

Assessing and testing knowledge can be undertaken in many different ways, for example, verbally, through interview or explanation, written using descriptive writing, multiple choice, and short answer questions, or through the use of diagrams by e.g. completing blank diagrams or recognition tasks with diagrams. However, each test format has its advantages and disadvantages in terms of, for example, what is being tested, familiarity of tests techniques by participants, duration of time available for participant testing. This thesis uses primarily short answer and multiple choice techniques, with two of the studies using a diagram based test, one in combination with written questions. The rationale for employing these test designs was driven by the information required by the study, as well as familiarity on the part of pupil participants of using written tests, and the practical considerations in respect of limiting the amount of class time pupils were missing.

3.7. Summary

The purpose of this chapter was to outline the problem space to be addressed in this thesis and the theoretical rationale behind the studies undertaken in this current research. The main aims of the thesis are to explore the use of an analytic framework that focuses on the properties of the representation in conjunction with cognitive requirements of the learner in order to identify cognitive components of a processing model of animation. If particular cognitive dimensions of the representation can also be identified then these dimensions may serve as a starting point for informing design of animation and/or learner guidance or assistance in using such representations for learning.

Chapter 4

Diagram Representation: A comparison of animated and static formats

4.1 Overview

This research investigates learning using animated diagrams of dynamic processes in order to begin to establish a cognitive process model for animation. In addition, this may inform about design issues for, and provide guidelines in relation to, learning with this kind of representation. The studies presented here begin this progression by comparing learning using either an animated or a static diagram of a dynamic system. The aim is to examine more closely the validity of cognitive benefits assumed to result from visual explicitness, by exploring potential differences in processing from different representational formats. The first study highlights important cognitive and representational issues specific to animation, which are examined in more detail in a follow up study, providing a clearer basis for the subsequent research in this thesis.

4.2. Introduction

Multimedia enables novel ways of representing information through different media formats and advances in graphical technology provide the facility for dynamic processes to be represented in animated as well as static form. Park (1998), for example, claims that animation can be an important instructional tool, serving such functions as, attracting and directing learner attention, representing dynamic domains, and in explaining complex system events (e.g. structural and functional relationships among system components). It may be true that animation by virtue of its motion, attracts attention, but does it attract attention merely to the overall moving image, thus, detracting from the individual components necessary to understand the system? Or does it draw attention to the actual dynamics taking place, especially if it is a multidimensional system or consists of a multifaceted dynamical system? Animation, by enabling visually explicit representation of temporal aspects, may 'explain' complex phenomena, but are these explanations explicit enough for the learner to obtain adequate comprehension? Although, this dynamic form may be more attractive to learners and may, therefore, be assumed to be educationally beneficial, comprehensive research of evidence behind the validity of this assumption is lacking.

Furthermore, diagrammatic research suggests that diagrams can facilitate cognition due to explicit perceptual properties of the representational format. The explicit depiction of components and relational aspects provides computational offloading precluding the need for the learner to 'work out' certain aspects of the diagram. A resulting assumption, therefore, could be that the more explicit depiction of movement offered through animation should be particularly beneficial for learning about dynamics, due to additional computational offloading for the learner. In contrast to Hegarty et. al. (1999), (where performance levels were shown to be related to individual spatial ability and the type of system in terms of its complexity - one moving component or several components moving simultaneously) the research in this thesis *provides* explicit visual representation of movement (through animated diagrams), precluding the need to 'work out' dynamic aspects and therefore reducing cognitive processing through computational offloading. This enables investigation into discovering the representational properties that may affect cognition and the consequent learning or understanding that takes place. The onus then, here, is on the interaction between the representational format and the learner, the interplay between internal and external representations on cognition by identifying particular cognitive benefits and costs of animation used to depict dynamic processes.

4.2.1. Summary of relevant research

Research into the effectiveness of computer animation for enhancing learning has been varied, with inconsistent results often due to methodological problems and variance across studies (Park 1998). Examples include the use of competing theories (dual coding, single coding, mental models), the large number of variables involved (text and animation vary according to lots of criteria - colour/black and white, degree of realism, type and complexity, textual reading level), individual differences (adults versus children, spatial ability, prior knowledge, intellectual ability, cognitive style), varied use of testing measures (recall, recognition, MCQ, problem solving tasks), research environment (situated versus experimental) (Large 1996) (see chapter 2 for more detail). Research into the use of animation for learning is, therefore, inconclusive, and leaves much scope for more rigorous research.

Several studies comparing the use of animated and static representations in varying domains also show no consistent evidence of improved learner understanding, suggesting that provision of a moving image may not necessarily facilitate overall conceptual understanding. According to theories of computational offloading the visual explicit depiction of movement should reduce cognitive processing and facilitate understanding of dynamics. However, several researchers have cited the possible complexities of processing dynamic illustration and multimedia (e.g. Kaiser et. al. 1992, Hoogeveen 1997, Large et. al. 1994, Stenning 1998). This research suggests that animation may be problematic for comprehension for several reasons: use of animation on diagrams results in an unmanageable increase of perceptually available information, especially where multidimensional dynamics are involved (e.g. Kaiser et al 1992); use of multimedia representations can result in cognitive or memory overload due to too much information (Kaiser et. al. 1992), due to problems in having to integrate multiple representations not always simultaneously available on the screen (Rogers and Scaife 1997, Hoogeveen 1997), and due to the transience of the information (Stenning 1998). This suggests that the visual explicitness and perceptual availability of information may, therefore, have thresholds in terms of their cognitive benefit.

Other research into graphical representation and cognition suggest that it is the particular forms of the representation (i.e. its representational properties) within a particular user context that will affect cognition (Green 1989, Scaife and Rogers 1996). This idea is confirmed by Zhang and Norman (1994) whose research into reasoning with graphical representation suggests that different representational formats of the same structure "can activate completely different processes" (Zhang and Norman 1994 p.118). Different processes, in turn, may result in different conceptual understanding. Therefore, the different representational structures of animated and static diagrams may generate different processes and consequently result in different understanding. Thus, it may not necessarily follow that the discovered cognitive benefits of static diagrams (e.g. reduction in cognitive processing through visual explicitness, perceptual availability of information) also hold true for animated diagrams. The representational format itself may be critical in the way that comprehension is realised. As the fundamental representational properties of animated and static diagrams differ, the kinds of cognitive processing and understanding that is gained from these formats may also differ. However, although these representational formats clearly display certain features differently, such as explicit movement depiction, both formats also display 'static' information. Thus, an animated diagram consists of a mixture of statically displayed information and dynamically displayed information. This means that when using an animated diagram learners need to attend to both of these characteristics of the representation. It might be that the attraction of the explicit dynamic depiction detracts from the underlying static aspects of the diagram. Investigating learning from both formats may provide a clearer insight into the differences in representational formats and their effects on cognition.

4.2.2. Rationale and aims of studies

Thus, it is the representational properties that dictate whether certain aspects of the representation are cognitively beneficial or not. It is investigating this that will give insight into the particular cognitive benefits or disadvantages of animation. One example is the "visibility" and "parsability" of a meaningful structure. This may be interpreted as the visibility of particular aspects of the representation and particular components within the information. In terms of an animated diagram this might refer to which aspects are most visible, and how easy or difficult it is for the learner to parse all the pieces of information imparted into salient groupings and into a salient order. Therefore, the studies in this chapter focus on the effect of the explicit dynamic depiction inherently found in animation on comprehension, as well as exploring issues related to parsing information from the diagram by looking for patterns of attention focus, evidence of particular complexities of the representations by examining differences in errors as well as accuracy.

The studies presented here were undertaken as exploratory studies looking at differences in cognition between static and animated representations of dynamic systems. The aim was to obtain information on the differences in processing between animated and static representations, to pinpoint more specifically the features of an animated depiction of a dynamic system that are different or result in different cognition from features of a static representation. Moreover, the studies aim to begin to understand more clearly the kinds of information that is noticed or overlooked, understood or misunderstood, in relation to particular representational properties. This should facilitate clarification of pertinent representational properties and learning requirements on which to base further investigation into the cognitive processing of animated diagrams.

To do this two studies were carried out, which looked generally at two issues *(i)* differences in understanding about a dynamic system using an animated or a static representation of the process, in order to tease out differences in representational properties and variations in consequent processing, and *(ii)* differences in understanding using two alternative approaches to learning with the representations, in order to provide some insight into relevant learning aspects using these kinds of representations.

4.3 Study 1: Comparison of animated and static formats of diagrammatic representation

The aim of this study was primarily to investigate the effects of media type, paper-based diagram versus computer-based animation, but the effects of design of the learning approach was also investigated. Diagrammatic representation of blood flow through the heart was used in CD ROM and paper format, to compare animated with static representation of the concept. Two different task presentations were also used to be compatible with the different type of learning that CD ROM presentation generates (an open freedom in information exploration) as opposed to a formal teaching situation (a structured guidance with information); (i) an open task where pupils were required to find out: how the blood flows in through and out of the heart; about blood that is rich in oxygen, and blood that has less oxygen and about the different chambers of the heart, and (ii) a structured task where pupils were given a worksheet with specific aspects for them to investigate.

4.3.1. Method

Participants

One hundred and twelve year nine pupils aged thirteen and fourteen years, from two Sussex community colleges participated in the study. Fifty three were male (mean age = 13 years 10 months; 166 months sd=3.2 months), and fifty nine were female (mean age = 13 years 11 months; 167 months sd=3.6 months). 'Blood flow through the heart' had not yet been covered in the curriculum. Pupils using the CD ROM all professed to be familiar with CD ROM use, and navigated the program with little difficulty. Pupils were informed that the purpose of the experiment was to investigate learning from different diagram presentations with a view to improving design.

Materials

Two types of information presentation were used; animated (CD ROM) or static (paper) information. Two types of task were given; 'open' or 'structured'. The same test was given to all participants.

(i) CD ROM condition. The 'heart' section of 'What's the Secret?' CD ROM from 3M Learning Software was used (see appendix 1 for example frame). This was run on a Macintosh Quadra 700 computer and on a Viglen PCI P.560 computer terminal. The program consisted of information covering varying aspects about the heart, including animated video presentation of blood flow through the heart, and accompanying text. Information needed for overall understanding of blood flow was found on separate parts of the program. Pupils were guided to the relevant areas prior to beginning their own investigations. This was to ensure that they did not miss relevant aspects of the information, which was a potential concern as *(i)* the information on the CD ROM is not confined whereas the static information was, and *(ii)* their participation time was limited. Pupils interacted with the program by selecting and clicking on areas of information or animated videos as frequently as desired. Pupils were provided with pens and plain paper to make their own notes while exploring the information if they chose.

(ii) Static paper condition. This consisted of colour printed information selected and taken from the heart section of 'What's the Secret' CD ROM (see appendix 2). The static information was designed to ensure that coverage of information relating to blood flow through the heart was as equivalent, as was possible, to the CD ROM information needed to complete the test. The resultant information consisted of three static diagrams presented in a coherent order to represent the different stages in blood flow as it progressed through the heart. Pupils were provided with pens to make notes on the information if they chose.

(iii) Tasks. These were of two types; an open task and a structured worksheet, designed collaboratively with a science teacher. The open task required pupils to do the following (see appendix 3 (i) open task).

> You have a friend Iona Heart, who is taking a first aid exam. Iona needs to know how the blood flows through her heart. In fifteen minutes use the CD ROM provided so that you can explain to Iona;
> How the blood flows in through and out of the heart.

About blood that is rich in oxygen, and blood that has less oxygen.
About the different chambers of the heart.

The structured task consisted of a set of questions which pupils completed on their own sheet as they worked with their allocated information (see appendix 3 (ii) structured worksheet). Half of the subjects in both the static and CD ROM conditions used the open task and the other half used the worksheet. The tasks in this study were designed to elicit information about pupil understanding of aspects that relate to a mixture of both statically displayed and dynamically displayed information of the cardiac system, as these aspects relate to the explicit differences between the two representational formats.

(iv) Post test. This consisted of a black and white diagram of the heart, which pupils had to complete within five minutes, demonstrating their knowledge of blood flow through the heart (see appendix 4). The test was a simplified version of the diagram taken from the CD ROM. The diagram was simplified in terms of the number of vessels entering and leaving the heart, as pupils in the pilot study found the original number of blood vessels too confusing. This was not considered to reduce evidence of their knowledge of blood flow through the heart. To complete the test diagram pupils were given blue and red pens and the eight following labels; ‘to body’, ‘from body’, ‘to lungs’, ‘from lungs’, ‘right atrium’, ‘left atrium’, ‘right ventricle’, ‘left ventricle’. They were instructed to use the blue pen for blood ‘less in oxygen’ (deoxygenated) and the red pen for blood ‘rich in oxygen’ (oxygenated), and use arrows to show where the blood enters, flows through, and leaves the heart. They were also required to put the eight provided labels in the appropriate places.

The materials were tested in a small pilot study, using four pairs of pupils in each condition, to ensure that the information, task and test were appropriate. The pilot study was also used to formulate the task instructions. The pilot study enabled the experimenter to assess CD ROM interaction within the restricted time allocation, so that relevant guidance could be given to participants in the CD ROM condition.

<u>Design</u>

Pupils participated in either the animated condition or the static condition, and used either an open or structured task. The experiment was therefore a 2 (animated or static) x 2 (open or structured) design. The two independent variables were type of information presentation, and type of task given. The dependent variable was the test score. Participants were assigned to work with information either in the animated (CD ROM) or the static (paper) format. Half of each of these groups worked from the 'open' task, the other half used the structured worksheet. All participants worked in pairs for fifteen minutes on their allocated information, followed immediately by the test, which was undertaken individually. Time allocation was decided as a combination of ensuring adequate time for collecting necessary information and restrictions from school curriculum activities. Pupils either participated in a classroom or small laboratory room, according to what was available in the school.

<u>Procedure</u>

As co-operative working was important to facilitate verbal interaction, pupils were allocated in pairs by the teacher on the basis of working well together. This method was adopted as data was wanted, not only on the quantitative analysis of test scores, but also on the qualitative analysis of the kinds of information noticed and the ways in which pupils gleaned this information (see chapter 3.5.5.). Sessions were, therefore, video recorded.

Animated condition. Participants sat in pairs in front of their allocated computer terminal, with the heart section of 'What's the Secret?' ready loaded. They were informed that they had fifteen minutes to explore the CD ROM to find out the required information. The same instructions were given verbally and in print so that participants could refer back to the task. They were told they could make their own notes if they so desired. Approximately five minutes was initially spent with the experimenter directing them to the most relevant areas of information on the CD ROM, (for example, an animated video of blood flowing in through and out of the heart) as the program covered several other areas relating to the heart, and time restriction limited the freedom of exploration. Pupils could ask for guidance if they were unable to find the information they needed, as navigation skills were not of interest in this study. After fifteen minutes participants were moved to separate tables to complete the test. Again instructions were given both verbally and in print. Blue and red pens were provided, as were the eight appropriate labels. Use of information or notes was not permitted for the test.

Static condition. Two classes participated in this condition. One class was given the 'open' task, the other used the structured worksheet. Participants were also given the same instructions verbally as in print. Participants again worked with the information in pairs for fifteen minutes. They completed the test individually, also being provided with blue and red pens, eight appropriate labels, and prohibited from using information or notes.

4.3.2. Results

Scoring Method: Four different aspects of the diagram, relating appropriately to the task and the structured work sheet, were chosen for analysis. One point was allocated for each of the following; (i) oxygenated and deoxygenated blood represented in separate sides of the heart; (ii) depicting different types of blood in the correct sides; (iii) correct labelling using all eight labels; (iv) correct depiction of direction of blood flow using arrows, or from labelling if arrows were not used. Subjects could therefore receive a score from 0 to 4. An inter-observer reliability score of 95% was achieved.

Analysis. The data were analysed to determine whether media presentation or task type affected learning about blood flow through the heart, and to determine the kinds of inferences made from the diagrams. The data are presented in three sections: *(i)* analyses of the effects of both variables on the overall test score; *(ii)* analyses of the effects of variables on selected areas of the test from which scores were obtained; *(iii)* analyses of errors made.

1. Analysis of both variables on the overall test score.

The means and standard deviations of the task scores are given in table 4.1.

Table 4.1. Mean test scores for media presentation and task type. (sd = standard deviation)

	structured worksheet	open task
CD ROM	**2.29 sd = 1.24**	**1.79 sd = .99**
paper static	**2.43 sd = 1.43**	**1.86 sd = 1.33**

A two way independent analysis of variance (ANOVA) was performed on the test scores (see table 4.2).

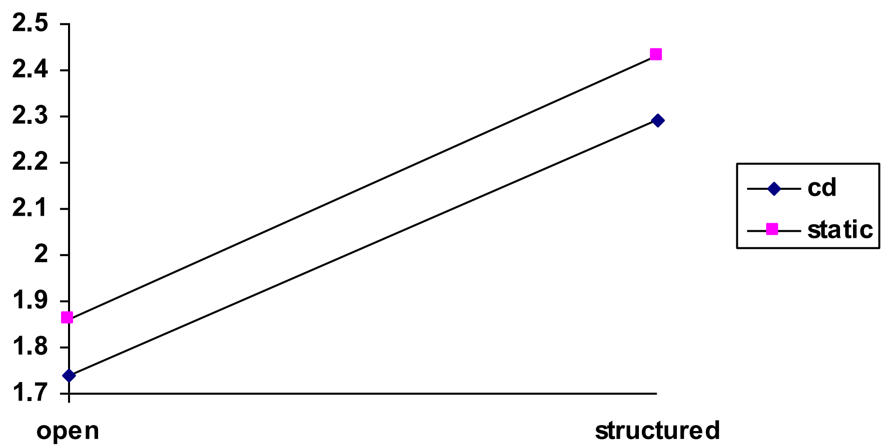
Table 4.2. ANOVA table for score.

	DF	Sum of squares	mean square	F-value	P-value
media	**1**	**.32**	**.32**	**.20**	**0.65**
task type	**1**	**8.04**	**8.04**	**5.08**	**0.02**
media/task	**1**	**3.57E-2**	**3.57E-2**	**2.26E-2**	**0.88**
residual	**108**	**170.71**	**1.58**		

No significant main effect of media format was found, thus media presentation did not significantly affect test scores. However, there was a significant main effect of task type ($p = 0.02$), Scheffe ($p = 0.02$). Those using the structured worksheet performed significantly better than those using the open task, regardless of media presentation. No interaction was found between the two variables (see figure 4.1).

Figure 4.1

Interaction line plot showing effects of media presentation and task types.



2. <u>Analysis of the effects of variables on selected areas of the test</u>

A series of two-tailed chi-square analyses were performed separately on the four selected parts of the test to determine whether media presentation or task type affected performance in particular areas of the test. No significant differences were shown in any section: blood in separate sides, chi-square 0.017, d.f = 1, not significant; blood in correct sides, chi-square = 0.013, d.f = 1, not significant; labels, chi-square = 0.505, d.f = 1, not significant; directionality, chi-square = 0.108, d.f = 1, not significant.

3. <u>Analysis of errors made</u>.

Despite the absence of overall significant differences on the four selected aspects, an inspection of individual scores in percentages showed that pupils made more errors with labelling and direction of blood flow.

84% = correct perception of separate sides.

69% = oxygenated and deoxygenated blood shown in correct sides

21% = correctly labelled.

34% = correct direction of blood flow.

Analysis of these aspects revealed differences in errors of interpretation of blood flow. The two most noteworthy errors were; showing blood to flow into the heart deoxygenated but to flow out oxygenated or vice versa; and perceiving the blood to enter the heart through the ventricles and leave via the atria. A chi-square was performed to determine whether pupil interpretations were affected by the two independent variables, and was found to be significant for 'in deoxygenated/out oxygenated' (chi-square = 6.00; d.f = 1; Fisher exact p = 0.02), and approaching significance for 'blood entry through ventricles' (chi-square = 4.03; d.f = 1; Fisher exact p = 0.06).

4.3.3. Discussion

Although overall understanding was not significantly different according to media presentation (animated computer and static paper diagrams), understanding was significantly affected by task presentation. Furthermore, analysis of specific areas of pupil learning showed significant differences in errors made, which may highlight important areas of diagram presentation in producing effective learning.

Much in line with previous research comparing static with animated diagrams (e.g. Betrancourt and Tversky 2000), the results showed no significant difference in overall test performance between computer and paper diagrams. Design of the paper information may have been a contributing factor. For both formats to be graphically similar and be as equivalent as possible in expressing the dynamics of the blood flow, the paper format consisted of three diagrams of the heart demonstrating the different stages of blood flow. This resulted in multiple representations rather than a single representation to express the information. Consequently, integration of separate pieces of information (to a certain degree) was required in learning from both the static and animated formats. Assimilation of multiple representations and information may not only be more difficult with computer presentation (Rogers and Scaife 1997), but also with paper presentation. One pupil specifically expressed difficulty integrating the information from three diagrams into the one diagram presented in the test. Comparison of diagrams involving one static representation could be beneficial in clarifying this point. The static diagrams was also lacking in specific depiction of motion cues, the motion having to be inferred from the differences between the three diagrams. This may have had a profound effect on those using the static presentation as Park (1998) found that the difference in performance between static and animated representations may be due to whether or not static diagram contains appropriate motion cues.

Pupils using a structured worksheet were shown to demonstrate significantly better understanding of blood flow through the heart than those using an open focused task. As diagrams contain large amounts of information in one representation the possibility of a gradual build-up of knowledge is reduced. It is left to the learner to decide which aspects are important and which aspects to focus on first or second. Sequencing particular aspects in separate sections may reduce confusion and result in a more logical and understandable order. This suggests primarily the importance of organising information for learning. Not only may it be important to guide learners towards specific pieces of information, but also to order the aspects they attend to, in such a way that it enhances integration of information. Focusing and sequencing relieves learners from deciding which aspects are important and in which order to 'read' information, which may reduce confusion and enable focus of attention on relevant aspects. This issue will be explored further in chapter 8.

Analysis of errors showed that the kinds of errors made differed according to presentational format. This verifies that different representations not only influence whether problem solving is easier or more difficult, but also generate different understanding, confirming that different representational formats of a common structure "can activate completely different processes" (Zhang and Norman 1994, p.118). This also suggests that certain aspects of a concept may benefit from being represented either in static or in animated format. Four particular aspects of comprehension of cardiac circulation were analysed for the purpose of this study; understanding of oxygenated and deoxygenated blood being confined to separate sides of the heart; depiction of oxygenated blood in the left side and deoxygenated blood in the right side; labelling; and direction of blood flow. Errors made in the test were primarily related to blood flow and labelling. As labelling the different sections of the heart and circulatory system are not highly relevant to processing dynamics, the implications of errors relating to blood flow only will be discussed here. The results suggest that either this subject matter was just less clear from the diagrams and/or was more conceptually complex to grasp. Understanding the blood flow may have been problematic for several reasons: *(i)* the static diagram did not explicitly show direction of blood flow, as it lacked appropriate motion cues, thus direction of flow had to be inferred from the labels (appendix 2). Pupils in the static condition predominantly depicted blood flowing in via the ventricles and out via the atria, suggesting that direction of flow in the static condition was problematic: *(ii)* on the animation there was copious simultaneous movement of different parts and different types of blood, making it difficult to see where each element was going and what each component was doing. Pupils made comments such as "stop moving" and used the diagram in stationary format to work out the blood flow. This supports evidence that multidimensional problems may not be aided by animation (Kaiser et. al. 1992). Multidimensional dynamics in this instance were not sequenced into separate dynamical processes (as advocated by Kaiser et. al. 1992), and resulted in a confused presentation of movement. It seems plausible that 'direction' could easily be misconstrued to show blood flowing in one colour and out the other, thus resulting in the confusion of oxygenated in, deoxygenated out. This finding also supports the principle that the design of the diagram in terms of its cognitive properties may affect understanding, and that attention to the cognitive dimensions of representation is important in understanding processing with particular representational formats. For example, in terms of role-expressiveness (Green 1989), the visibility and parsability of salient pieces of information from an animated diagram may be insufficiently available to the learner, resulting in ambiguous presentation of information and subsequent errors in learning as cited above.

Overall, improved understanding of circulation in the heart was not apparent from the use of animation. Although animation increases perceptually available information and may therefore be assumed to reduce cognitive processing, this increase may actually have a different effect. *(i)* viewing an animation may result in cognitive effort and 'working out' of dynamics being reduced to such a degree that learning is ineffectual, *(ii)* the increases perceptually available information is a result of explicit dynamic depiction and may result in dynamic information overload, increasing cognitive demands, *(iii)* perceptual availability may not necessarily facilitate understanding. Although animation may be more explicit "our perceptual appreciations do not spontaneously form the basis of our conceptual understanding of dynamics" (Kaiser et. al. 1992, p.686). Anderson (1995) proposes that conceptual knowledge is based on the meaning of a representation. Errors in pupil learning suggest that comprehension of the function of the heart was lacking. For example, analysis of depiction of direction of blood flow showed errors in representation of blood flowing into the heart oxygenated and out deoxygenated, or vice versa were more prevalent in the animated condition. This seems to attribute to the heart a similar functional role as the lungs, resulting in errors in understanding blood flow. Functional information was not clear from either presentation format. If meaning is important in conceptual understanding then awareness of the function of the heart, or its components, may constrain inferences made from the diagram. For example, if the function of the ventricles to 'pump' blood out of the heart is made explicit, then this constrains the way that the blood is likely to flow. The function of a represented structure may critically influence diagram interpretation. This also raises the issue of external internal interaction and the effect of prior knowledge on the kinds of information noticed and retrieved from diagrams (e.g. Lowe 1994 expert/ novice differences).

However, this error could also be seen to be a result of a representational feature which can conceptually be seen to relate to Green's (1989) concept of hidden dependencies in the role that they play in cognition. In the context of this research understanding the way the system works may be dependent on understanding the functions of particular components in their relation to the functioning of the system as a whole and understanding links between the heart and other processes within the lungs and the body. These 'peripheral' links and relationships (to other interrelated processes) may be 'hidden' in the information presented in the animation used in this study. Thus, the functions of individual components of a dynamic system may be considered as dependencies, and a process within a process may be a peripheral dependency for understanding the whole concept of cardiac circulation (also see chapter 2.3.2. and 3.2.2. for detail on Cognitive Dimensions concept).

4.4. Study 2: Investigation of knowledge construction from animated diagrams

Study 1 demonstrated that different representational formats of the same process result in different understanding, that understanding multidimensional dynamics is not necessarily facilitated by animation alone, comprehension being dependent on other factors. However, time restrictions within school and pupil participation meant that pupils were unable to participate in further assessment such as talking more specifically through the process either during their interaction with the diagram, or afterwards, thus, showing more explicitly where the difficulties in comprehension lay. Study 2, therefore, examined more specifically, using qualitative data, the differences in ways that pupils worked with animation and static diagrams of blood flow, which parts they found hard or easy to understand, and investigated cited claims about animation, for example, complexity from increased availability of information, salience of certain aspects.

4.4.1. Method

Participants

Twenty two pupils aged thirteen and fourteen years from a Sussex Community College participated in the study. Thirteen were male (mean age = 14 years; 168 months, sd = 6.9 months) and nine female (mean age = 14 years 2 months; 170 months, sd = 2.5 months). Pupils were informed that the purpose of the study was to explore the kinds of information they could retrieve from the diagrams they worked with.

Materials

Two types of information presentation were used:

- *Animated condition*: The same CD ROM programme was used as in study1 and was run on a Macintosh Quadra 700 computer terminal. However, in this study pupils worked only with the animated diagram. Text information was obscured and introduced only if pupils found it too difficult to retrieve information from the diagram alone. The purpose of this was to enable specific focus on the effect of animation on understanding, by removing other variables that could contribute to learning (see appendix 5 for example frame). Pupils interacted with the programme only by clicking to view the animation again.
- *Static paper condition*: This consisted of a single diagram taken from study1 showing the heart and the lungs with blood vessels labelled to body from body, to lungs and from lungs (see appendix 6). This diagram was used initially without the accompanying text to again to avoid learning from other media than the diagram, e.g. textual explanation.
- *Task:* Pupils were asked to use their allocated diagram to find out as much as they could about the pathway of blood flow through the heart, how the heart pumped blood and how the valves worked. The task set was fairly general in order to discover the kinds of things noticed or attended to by pupils and the kinds of inferences made, whereas a specific task would focus their attention on particular aspects.
- *Tests:* These were of two types (see appendix 7);

i) A written questionnaire comprising a combination of multiple choice questions and free recall questions. This kind of test enabled access to information about factual, functional and conceptual knowledge, as well as specifically about blood flow pathways.

ii) A black and white blank diagram of the heart, which pupils had to complete, demonstrating their knowledge of blood flow through the heart. This test facilitated representation of knowledge in a similar format to the learning situation. The test was a simplified version of the diagram taken from the CD ROM, as in study1. Pupils were instructed to use the blue pen for blood ‘less in oxygen’ (deoxygenated) and the red pen for blood ‘rich in oxygen’ (oxygenated), and use arrows to show where the blood enters, flows through, and leaves the heart. They were also required to put labels indicating where the blood was flowing to and from in appropriate places.

Design

This study primarily used verbal protocols, in order to obtain richer data on the kinds of observations and understandings that were made by pupils. Pupils worked either with a computer presented animated diagram or with a static paper diagram. All participants worked in pairs with the researcher for approximately half an hour on their allocated information, but those using the static diagram were also given an opportunity to briefly work with the animated version, to investigate any further information. All sessions with pupils were video-recorded.

Procedure

Pupils were allocated in pairs by the teacher. One of each pair was given a few minutes to study the diagram alone. Time allowed was dependent on the individual pupil, but generally did not exceed five minutes. This flexibility was to allow for individual differences and was not considered to violate findings as direct comparison between pupil learning was not being made. Pupil 1 was then required to explain to pupil 2 what the diagram was showing. They then worked with the information together participating in discussions between themselves. The researcher intervened only when pupils were unable to glean any more information, by asking open questions or more specific questions depending on pupil progress (see appendix 2d for examples). The data was collected in this way to try to find out more specifically the kinds of information that was clear or unclear, and the ways in which information was pieced together.

4.4.2. Results and Discussion

Analysis in this study was made from transcripts taken from video-recordings of all sessions. The results reported here are descriptive due to the methodology and kind of data collected, and each pertinent aspect is identified and discussed simultaneously.

(i) One interesting and unexpected finding was that animation appeared to generate artificially high confidence levels, increasing complexity and preventing learners from paying

appropriate attention to the information. For example, all pupils working with animation expressed confidence of their understanding of the diagram, but when asked specific questions e.g. about blood pathways, they were unable to give clear or complete answers. This suggests that animation provides inappropriate computational offloading precluding the possibility of effective learning, by giving the learner false certainty of gained knowledge. Only when learners had to explain the process or were asked specific questions, were they aware of their lack of understanding.

*(ii)*Two pairs made inaccurate interpretations of blood flow, perceiving blood flowing in one colour but flowing out the other. This was interpreted as perceiving oxygen exchange taking place inside the heart. Furthermore, these pupils stated that the function of the heart was to 'clean the blood' i.e. to oxygenate the blood. This equates with errors found in study1, also suggesting that meaning and interpretation of a representation may be related, and that understanding is dependent on aspects from the diagram that were 'hidden' or peripheral to the system depicted i.e. functional relationships and the processes within the greater system.

(iii) Some pupils expressed difficulty with focusing, suggesting that directing attention to pertinent pieces of information is important. With each viewing of the animation pupils were able to explain blood flow in more detail, and combine this information with contraction and valve action. Thus, they appear to take in small amounts of information at one time, gradually combining their knowledge with previous pieces of information, which in line with previous research, provides evidence of incremental reasoning (e.g. Hegarty 1992, Narayanan et al. 1994). This kind of reasoning highlights the importance of parsing or sequencing knowledge acquisition. However, distinct patterns of attention became apparent when pupils were asked questions about specific aspects. For example, all pupils primarily focused on blood flow. After one more viewing four of the pairs noticed the heart contracting. No pupils spontaneously noticed valve action and were specifically directed to this component by the researcher. In terms of the concept of role-expressiveness this suggests that certain areas may be identified as salient components to parse, and have a particular coherent order for parsing.

4.5. General Discussion

These two studies, then, have made some progress towards establishing aspects of the representational format that affect cognition. As the focus of this research is on animation, this discussion will primarily refer to findings that are pertinent to animated representation and its further investigation. The discussion is structured around the representational properties evident from these studies and their cognitive effects, under the following headings; complexity of the representation, parsability of the representation and hidden processes or peripheral dependencies.

4.5.1. Complexity of the representation:

Complexity of the representation may be due to several inherent characteristics of animation: multidimensional dynamics, speed of motion, multifaceted moving components, transience of information, difficulty in focusing attention, salience. Stenning (1998) suggests that such complexity may be a result of the following characteristics of animation; i) evanescence, the problem of memory load is enhanced by the 'transient form' of animation, which means that all sequences of movement need to be held in memory to integrate with new pieces of information to understand the process; ii) expressiveness (as defined by Stenning 1998, see chapter 1); Animation demands a more expressive representation, as all aspects of a process must be shown simultaneously, making focus on one aspect difficult; iii) control, the evanescent form means that learners are unable to reaccess pieces of information as that information is no longer perceptually available. Learners, therefore, have no control over what information is viewed, or for how long, as information is continuously passing by.

These studies have shown evidence of some of these features and suggest ways in which they affect cognitive processing with animation, all of which appear to fall within a more general category of ‘visual explicitness’. An animated diagram of a dynamic system shows the motion aspects and changes that occur more visually explicitly than a static representation. Visual explicitness, however, results in an increased availability of information about dynamics. In terms of computational offloading this visual explicitness should reduce cognitive processing through increased availability of the dynamic information. However, although this information is visually explicitly available, the learner may not always be able to make good cognitive use of it, cognition possibly being affected in the following ways:

(i) A learner is aware that all this information is visually available, and can ‘see’ what is happening (on a superficial level) while the animation is running. This can result in overconfidence in the actual knowledge accrued from the diagram, which in turn inhibits efforts at comprehensive learning through cognitively working out relevant aspects from the

diagram. Study 2 showed that learners were prematurely ready to declare their understanding of the process, and that when required to explain the process were unable to give any comprehensive account of the system, clearly showing their knowledge was lacking.

(ii) Visual explicitness in an animation inevitably results in an increased amount of information, as all dynamic changes occurring in the system are depicted. This seems to contribute to the cognitive complexity of the representation for the learner who has more information to attend to and more aspects to focus on. Thus, not only is there additional cognitive work (as the learner is required to choose which aspects to focus on), but also some information may be missed altogether. Evidence for this came from study1 where dynamic information load and the transience of the representation made it difficult for pupils to identify all the events taking place and caused some pupils to look at the diagram in static mode to try to work out the blood flow.

(iii) The visually explicit depiction of dynamics may also result in distraction for the learner. In order to accurately understand the dynamics the learner is required to distinguish one dynamic change from another. Study1 showed evidence that some areas of blood flow were more confusing than others, for example, blood flow inside the heart. Here pupils became confused about where the blood was actually flowing inside the heart, the movement possibly detracting their ability to perceive that different blood colours flowed through different sides, and therefore resulted in a false perception that blood was flowing in one colour and out another. This consequently resulted in a false inference that blood is oxygenated in the heart.

(iv) Increased amount of perceptually available information also means that pupils have to remember more pieces of information. In both studies pupils found it difficult to follow the complete blood flow pathway. They were able to remember some aspects of it, but not all, which was demonstrated in study 2 when pupils were describing blood flow to their peers, they began by explaining the first couple of steps in the blood flow cycle, but then were unable to continue. This particular aspect of cognition may be compounded by lack of learner control over the information. The inherent transient nature of the representation prevents easy reaccess to information.

In summary, then, animation contains more perceptually available information than static by explicitly illustrating dynamic aspects of a process with varying consequences. Explicit dynamic depiction may mean that less ‘working out’ of dynamics is necessary, lessening cognitive processing to such a degree that no specific inferences or false inferences are made and consequently learners fail to achieve deep comprehension. Increased perceptual information on animation means more dynamic information, the level of which may significantly affect cognition. Therefore, visual explicitness of this representational format has implications cognitively in terms of learner confidence, attention focus, attention distraction, and memory, all of which affect processing and subsequent learning.

However, despite some disadvantages, animation may provide benefits over use of static diagrams alone. When attention was focused and pupils were directed, animation imparted more information about the dynamics of the system than pupils could obtain from the static diagram, for example, they could construct clearer models about how the valves worked and how the heart 'pumped'.

4.5.2. Parsability of the representation

Although there are potential educational advantages in terms of understanding motion aspects more clearly, animation is a complex representation with which to work, and appears to be cognitively demanding in certain respects. Kaiser et. al. (1992) showed that animation was beneficial where only one perceptual dimension of motion was displayed. Such a breakdown, or parsing, of the motion may add clarity, for example, looking at the path of the deoxygenated blood and oxygenated blood separately, or alternatively depicting one particle moving through the entire sequence of blood flow, could illustrate the blood path more unambiguously. However, despite multidimensional aspects of motion, these studies showed evidence of patterns of attention focus on varying motion features of the diagram suggesting that gross parsing of dynamics may take place. This ‘automatic’ learner parsing corresponds to the proposal of domain parsing of dynamics (see chapter 2) (here the domain dynamics are classified as blood flow, valves, muscle action). However, it appears that parsing at a more specific level, the level of dynamic change is also important in order to segregate the individual dynamic changes that take place. This would enable learners to identify all the different components, easing the problem of distraction, difficulty in focusing attention and may aid integration of information. There is evidence that investigating the parsability of animated diagrams would be particularly pertinent in view of the importance of reducing complexity through parsing information. These studies point to potentially salient components to parse and a coherent order of parsing.

4.5.3. Peripheral dependencies of the representation

One other main aspect that seemed to emerge from this study was the potential importance of understanding links with other processes that are ultimately integral to the process being displayed. For example, there seems to be evidence that pupils misunderstand the functionality of the heart, perceiving oxygen exchange to occur in the heart. One explanation may be that the information links between processes that are not primary to the displayed process are lacking. In this context understanding the system as a whole (cardiac circulation) is dependent on understanding the relational functions of processes peripheral to the primary process (in this instance the lungs). These aspects appear to be ‘hidden’, and therefore may result in misunderstanding. This issue will be discussed further in chapter eight.

Despite cited disadvantages, animation imparted more information about the dynamics of the system than pupils could obtain from a static diagram, for example, they could construct clearer models about how the valves worked, how the heart 'pumped' and the temporal relations between the two. There was evidence of patterns in attention focus, i.e. there were similar patterns across pupils in the order that information was selected to be parsed. Not only does this suggest the kinds of aspects that may more visually discernible, but also confirms previous research demonstrating ‘incremental reasoning’ and the intuitive need to take in small amounts of information at one time, gradually combining their knowledge with previous pieces of information (e.g. Hegarty 1992, Narayanan et. al. 1994). This also confirms the importance of parsing or sequencing information for knowledge acquisition.

4.5.4. Summary

There are dichotomous findings here as the results suggest that animation can provide more information about dynamics than a single static representation, but that it is too cognitively complex in a non-interactive, illustrative capacity, resulting in cognitive overload and ineffectual learning. However, animation depicts more information about motion changes, temporal sequences and relational effects of motion or temporal aspects on the dynamic system than a single static representation. Therefore, there is a conflict between providing more ‘explicit’ information of dynamics in combination with increased cognitive and memory load and complexity, versus more implicit information about dynamics combined with reduced complexity, and as a consequence, with reduced dynamic information as well. Therefore, provision of an animation in and of itself may be too cognitively complex - being too fast, lacking in learner control, and impeding attention focus - to generate learning of a dynamic process or system, and more detailed investigation into the cognitive dimensions of representation for animated diagrams is needed. Explicitness itself may be identified as a CDAR, where a more explicit depiction results in tradeoffs of potentially more dynamic information available, but cognitively difficult to manage.

4.6. Limitations of studies

Several problems with the design of these studies can be identified, and are noted here in order to explain the basis for modifications and improvements of the design of subsequent studies.

(i) Materials

As this was an initial exploratory study to identify in more specific detail properties and learning using animated diagrams, a computer presented diagram was taken from a commercial CD ROM. Although this served the purpose for the present studies, several disadvantages of this particular material became apparent. The particular design of the diagram may have affected learning in, for example, its clarity (or lack of) of depiction of direction of blood flow, links with other processes in the lungs and body, and the speed of the depiction of the diagram. Also by using a pre-designed animation there was no facility to manipulate particular aspects of the representation for research, such as, isolating or changing particular aspects of the diagram. It also meant that there was no facility for the learners themselves to control or interact with the representation, such as stopping and starting the animation, or slowing the speed. Being part of a CD ROM topic, it was also designed to be one part of a larger amount of information, and as such was supportive to other media information. Taking these aspects into consideration it seemed more appropriate to design and build an animated diagram that could be productively used for this research (see chapter 4).

(ii) Testing

A more thorough investigation into previous knowledge and experience with this type of diagram may have enabled a clearer understanding of how pupil inferences were achieved and differences between pre and post test conceptual knowledge. On the basis of this pre testing was used in future studies where analysis of these differences was required. The post test here was also designed to tap broad areas of understanding, some of which it became apparent were irrelevant to the specifics of cognitive effects of animation. Therefore, tests in subsequent studies were designed to focus more specifically on those particular features of animation being investigated.

4.7. Conclusion

Although this study did not demonstrate improved learning from a particular diagram format, it has demonstrated that different representational formats of the same process result in different inferences made. So far this research has exposed the complexities of presenting dynamic systems as animated diagrams for learning, but has also shown the enhanced level of information imparted over static representations of the same domains. These studies have begun to try to identify particular properties of animated diagrams (e.g. visual explicitness, multidimensional movement, transient information, high quantities of information, lack of salience) that could be analysed in terms of identifying important cognitive dimensions of representation for comprehensive understanding (e.g. visibility, hidden/peripheral processes, parsability) and investigating different design issues in relation to these dimensions. Overall these studies suggest that the use of animated diagrams to facilitate understanding of a dynamic process is not merely a matter of providing visually explicit information. There is more for the learner to achieve in understanding from this kind of representation than 'seeing' the depicted dynamics. The visual explicitness of dynamics in theory supplies the basis for a fuller understanding of dynamic systems, but the learner is required not only to 'see' (which in itself is a mammoth task from animation due to the large amount of transient information) the dynamics, but also to interpret the meaning behind the changes that are occurring in the representation, and to integrate all of these pieces of information into a coherent understanding of the system as a whole. The next chapter (chapter five) describes steps taken to address some of the limitations uncovered in the studies presented here. The subsequent three chapters (chapters six to eight) present studies addressing issues specifically related to identifying graphical change, interpreting graphical change and domain parsing of animated diagrams.

Chapter 5

Research Modifications

5. 1. Introduction

Chapter three in this thesis identified the fundamental form of animation and chapter four began an investigation into the general advantages and cognitive disadvantages of learning with animation. These comparative studies of animated and static representations showed differences in learning, some of which may be attributed to the structural differences between the presentational formats. Thus, the studies highlighted particular properties of the animated representations relevant to cognitive processing that can be isolated for further investigation, for example, the effect of visual explicitness of dynamic change on cognition. Overall these properties seem to be related to the salience and interpretation of individual dynamic components (the degree to which the representation can be dynamically parsed – see chapter 3.3.1.) and the integration of these and domain specific aspects of the representation (the degree to which domain parsing and integration takes place). Particular properties are defined more specifically and related to the proposed learning model (chapter 3.3.2.) at the beginning of each of the following relevant chapters as a basis for investigating the effects of animation properties. However, studies one and two also highlighted issues relating to both materials (animations and assessment) and methodology that need to be addressed. The purpose of this chapter is to address those issues and explain measures taken to improve these aspects for subsequent studies.

5.2. Limitations of studies one and two

Chapter four identified some limitations of studies one and two, particularly those relevant to subsequent investigation into cognitive processing with animation. The main limitations apparent were those relating to certain materials used and aspects of the methodology.

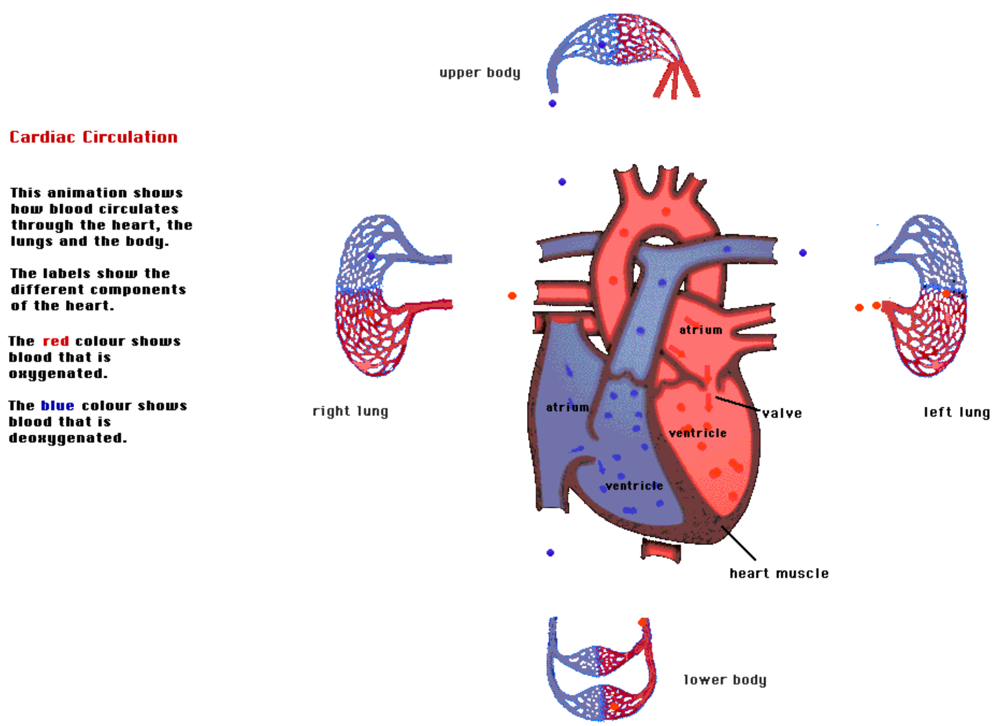
5.2.1. Changes in materials

From results of studies one and two it became apparent that the animation used had several weaknesses for research in this area. At the initial stages of the research choice of an animation was confined to one that was already produced on CD ROM. However, it transpired that this particular diagram was deficient in the following ways: *(i)* motion depiction of blood flow contained no directional cues, such as arrows, causing the static comparison to lack explicit directional cues and be shown in multiple static diagrams, *(ii)* the animation on the CD ROM was not 'stand alone' and was designed to be only one part of a collection of pieces of information for a larger topic, therefore could be considered deficient in some aspects of information display, *(iii)* the animation was non-interactive and could not be manipulated by the learner to stop, start or slow it down, *(iv)* but most importantly, a pre-developed CD ROM precluded the researcher from manipulating the animation to investigate pertinent aspects of cognition. Therefore, an animation specifically for the purposes of this research was designed and built using Macromedia Director.

This software was chosen on the grounds of its ease of implementation and the facilities it provides for customising by the researcher, and interactivity for the learner. The animations were designed and built to be appropriate for pupils, between the ages of 12-14 years, learning the principles of cardiac circulation (heart) and gas exchange in the lungs (respiration). These topics were both appropriate to the school curriculum of the targeted age group. Both animations were created using Macromedia Director, and were designed in colour to match conventions for representing oxygenated (red) and deoxygenated (blue) blood, and for representing oxygen (red) and carbon dioxide (blue).

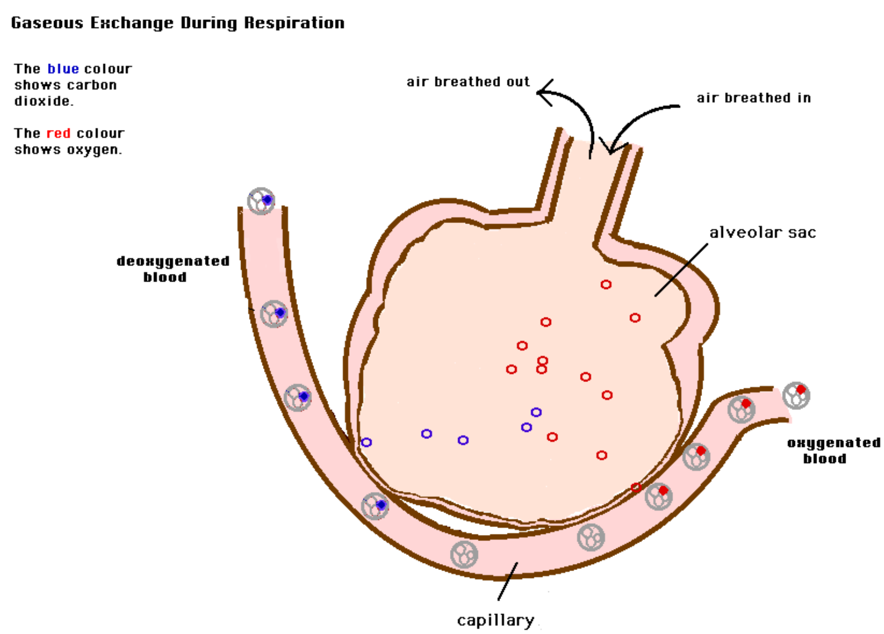
The basis for the design of the heart animation (see fig. 5.1 for example frame) was taken from The Cardiac Cycle CD ROM (Andromeda), with additional components such as the lungs and upper and lower body, and incorporating a minimum amount of learner control. The final animation consisted of ninety four frames running at fifteen frames per second (see CD ROM provided). The number of frames used was a product of the number needed to depict blood flow changes as smoothly as possible, the speed was selected such that the animation depicted changes fairly smoothly, but not so fast that changes became imperceptible.

Figure 5.1. One frame from the heart animation



The basic graphical outline design of the respiration animation (fig. 5.2.) was taken from the BBC GCSE Bitesize web page (www.bbc.co.uk/education/gcsebitesize/science-biology/humans/breathing_rev.html), with changes being made to some components and dynamic aspects of the diagram. Discussion with science teachers from the school involved in the research led to some minor alterations, which were made accordingly to the animations. The final animation consisted of fifty frames running at eight frames per second. Again the number of frames used was a product of the number needed to depict motion as smoothly as possible, and the speed such that motion was depicted smoothly but perceptibly. Both of these animations were used in studies three and four, but only the heart animation was used in studies five and six.

Figure 5.2. One frame from the respiration animation.



The animations were also designed more specifically for this research by contextualising the diagram prior to animating it, i.e. providing information for the learner so that their processing was directed specifically to areas of investigation. The rationale behind this was as follows: any system or process usually consists of several components that, alone, may be foreign to the learner. These individual components and their function may be vital for understanding the process as a whole. However, a novice to the domain may first need to see the main components of the diagram in context before being able to integrate them into the dynamic aspects of the system. Thus, introducing an animation of the complete system straight away may result in the learner having to pay attention to parts of the diagram or take learning steps that were not applicable to the research being undertaken. As the focus of the research is on dynamic change, the diagram was first shown to learners in static form so that the main diagrammatic components (e.g. the heart, the lungs, the body) could be specifically identified to the learners by the researcher. This meant that cognitive effort would hopefully be directed towards the dynamic aspects of the diagram. The animations were, therefore, designed to appear on the screen initially in static format so that the learner could familiarise themselves with the context of the diagram and the relevant component locations, and so that the researcher could explain important aspects of the diagram that were not specifically related to the dynamic aspects being investigated (e.g. that the red colour represented oxygenated blood and the blue colour represented deoxygenated blood).

5.2.2. Methodology

In study 1, pupils worked in pairs to encourage verbal interaction and all sessions were video recorded. Data collected was twofold: quantitative from test scores and qualitative from video analysis. In study 2 data was primarily qualitative from video recordings of pupils both explaining diagrams to one another and responding to researcher questions. Although, these methods of collecting data were still considered appropriate, certain aspects were refined to facilitate improved data about processing using animated diagrams. As pointed out in chapter three both quantitative and qualitative data positively contribute to understanding models of cognition, therefore, both methods were implemented in the subsequent studies.

Paired participants: For qualitative data collection pupils worked in pairs to facilitate verbal protocols while working with animation. Pupils either discussed together or one explained to another, depending on the appropriateness for the particular study. Individual participants: However, pupils also worked individually with the diagrams (with no interaction with either peers or researcher) in order to preclude the potential cognitive advantage that explainers may have through ‘explaining’. The self explanation effect suggests that through self explaining the learner acquires a conscious awareness of mismatches between internal representation and external representation, which facilitates the learner to move towards clearer understanding (Chi 1997).

5.3. Introduction to subsequent studies

The purpose of this section is to provide background research particularly relevant to the current studies and a brief outline of the relevant learning aspects for understanding the graphical change of animation. This introduction, therefore, consists of a summary of relevant issues about cognitive interaction that are (or may be considered to be) pertinent to animation. It then defines the properties of animation being investigated in the studies showing how these relate to the animations and defines the relevant aspects of the learning process. Through this the rationale and aims of the studies will be explicated.

To recap from chapter two, although research has demonstrated evidence for cognitive benefits of diagrammatic representation, the cognitive benefits of diagrammatic animation may not have the same underlying characteristics. So far, empirical research into the effectiveness of computer animation for enhancing learning is inconclusive and claims for its cognitive value for depicting dynamic requires further investigation. Comparing learning from animated and static diagrams may serve to extract information about the ways in which different representational formats might activate different cognitive processes, as the representational format may be critical in the way in which comprehension is realised (c.f. Zhang and Norman 1994). However, prior research into comparisons of static and animated diagrams shows no consistent evidence of improved understanding, (e.g. Tversky 2000). Studies one and two of the current research comparing the effects of static over animated diagrams of a dynamic process, for students learning the principles of cardiac circulation, suggested that provision of a moving image does not necessarily facilitate overall conceptual understanding. Findings suggested that although visual explicit representation of movement, in theory provides the potential for a clearer understanding of dynamics, it appears that providing such explicit representation increases the cognitive demands on the learner. The multidimensional aspect of movement depiction increases the dynamic events for the learner to attend to. The large amount of transient information in the animation increases cognitive load by increasing the amount of information that needs to remembered from one frame to the next. The learner is required not only to 'see' all of the graphical changes (which depict the dynamics) taking place, but also to interpret the representational or conceptual meaning behind the changes. The following three chapters, therefore, focus on particular critical cognitive aspects of interaction with animated graphics. The next two chapters (chapters six and seven) look at the process of cognitive interaction with animated diagrams, focusing on what and how learners see and interpret in terms of graphical change, and whether this is affected by complexity of the animation defined in terms of memory overload. The following chapter (chapter eight) focuses on exploring the integration process of animated information from the diagram.

5.3.1. Graphical properties of animation

Two principal factors are used in the studies in this thesis as a basis for examining the effects of specific properties of diagrammatic animation on learning: *(i)* identification of relevant CDAR of the representation, such as graphical properties of animation, *(ii)* the learning process itself when using this kind of representation. Chapter three identified some specific features of animated representational formats, that may be beneficial (or not) to cognitive processing. These were described in under the headings of multidimensionality, transience, visual dynamic explicitness (see chapter 3 for more detail). The current studies focus on how learners read and understand graphical change taking into account the complexity of such representations. Therefore the representational properties investigated here are transience, multidimensionality and graphical change, the related CDAR being memory overload, dynamic information load and visibility of graphical change.

5.3.2. Cognitive dimensions of animated representations (CDAR)

The identified inherent features of animation all have implications for cognitive processing of animated representations. Subsequent studies in this thesis examine animation in relation to the following possible cognitive dimensions.

(i) complexity

Transience (memory overload quality) and multidimensionality (dynamic information load) are both features of animated representations likely to affect how learners process or read graphical change. These features may contribute to complexity of the representation in terms of memory overload. In this study complexity of the animation is defined in relation to amount of information and dimensions. Broadly speaking complexity relating to dynamic information load can be defined by the number of dynamic changes or events that occur. The more different changes and events that take place, the more facets the learner is required to notice and interpret, and the more information the learner is required to remember from one frame to another, the more complex the representation is likely to be. Table 5.1. shows how memory overload has been categorised in relation to the animations used in this study. It can be seen from the table that overall there is a higher quantity of dynamic changes that occur in the circulation animation than the respiration animation. As a result of this categorisation the circulation animation was classified as complex and the respiration animation classified as simple.

(ii) salience and interpretation

The dynamics of an animated diagram are depicted through graphical change, which needs to be perceived, identified and interpreted by the learner. This can be seen in terms of the salience and interpretability of particular graphical changes. Table 5.2. shows salient features and the required interpretation of graphical change in relation to the animations used. Salience of graphical elements is identified in terms of their dynamic features in relation to one another in the animations used, to allow comparisons to be made between graphical elements and the two animations. The terms used under each column are, therefore, subjective to these animations rather than generic descriptions of the dynamics. The table shows that graphical elements in the circulation animation have more variance in their dynamic features than do the graphical elements in the respiration animation.

5.3.3. The learning process

Although both individual prior knowledge and learning tasks may differ the important goal for any learner is to be able to understand the process or system that the animated diagram is depicting. In cognitive terms the learner is required to focus on salient pieces of information, perceive the individual motional components, interpret what it is they are representing (not only graphically, but also dynamically), relate the motional aspects to the static aspects of the diagram, and integrate all of this information into a coherent model of the process. Describing this process is the beginnings of a formulating model of learning that could usefully be applied to working with animation. Park (1998) maintains that animation serves to attract and direct attention, but Lowe (1999) found that novice learners focused on (their attention was directed to) information that was perceptually salient rather than thematically relevant. However, it is likely that more is needed, cognitively, than just salience in order to understand an animation. Although animation may be more perceptually explicit “our perceptual appreciations do not spontaneously form the basis of our conceptual understanding of dynamics” (Kaiser et. al. 1992, p.686). Anderson (1995) proposes that conceptual knowledge is based on the meaning of a representation. Studies one and two suggested that a lack of explicit information about the function or reasoning behind a system obscures the overall meaning of the representation. However, the overall meaning of the representation may also be affected by potentially earlier processing of the dynamic information in terms of its salience and interpretation. Thus, it seems likely that understanding the meaning of the graphical changes that occur would be of paramount importance in building an appropriate mental model of the system. The understanding of the change may also serve to direct novices of the domain to thematically relevant as well as perceptually salient aspects. Once the learner has perceived and interpreted changes within the diagram, these pieces of information need to be integrated and relating inferences made about function and causality of the system depicted, but the focus of this chapter is on processing graphical change.

5.3.4. Summary

This chapter has explained the motivation for designing and building purpose built animations for subsequent research in this thesis. This enabled the researcher to manipulate the animation design in order to investigate particular pertinent aspects of cognitive processing with animation. The definition of complexity in relation to each animation for the purposes of this research was described, the aim being to explore the effect of these levels of complexity on particular aspects of the learning process, namely, noticing and identifying dynamic change (this refers to awareness that a change is occurring, and identification of the details of those changes), interpreting dynamic change and integrating this information from the animated diagram. The following three chapters present studies and their findings that explore these issues.

Table 5.1. Identification of levels of complexity

(i) **Dynamic information load**

- Number of moving parts (object action)

Circulation	Respiration
Blood Heart Muscle Valves Atria and ventricles	Blood Oxygen Carbon dioxide

- Number of directions of movement

Circulation	Respiration
Blood – Heart to right lung Heart to left lung Heart to upper body Heart to lower body Right lung to heart Left lung to heart Lower body to heart Upper body to heart Inside right side of heart Inside left side of heart	Blood through capillary Carbon dioxide to alveolar sac Oxygen to capillary Non directional floating in alveolar sac of carbon dioxide and oxygen

- Number of static locations of movement (to and from)

Circulation	Respiration
Heart Right lung Left lung Lower body Upper body	Capillary (from body to body) Alveolar sac Blood cells

- Number of objects that move from one place to another

Circulation	Respiration
Oxygenated blood Deoxygenated blood	Blood Oxygen Carbon dioxide

- Number of sections demonstrating the process

Circulation	Respiration
Blood from heart to right lung	Deoxygenated blood enters capillary
Blood from heart to left lung	Carbon dioxide diffuses into alveolar sac
Deoxygenated blood into oxygenated blood	Carbon dioxide is breathed out
Blood from right lung to heart	Oxygen is breathed in
Blood from left lung to heart	Oxygen diffuses into blood
Enters left atrium	Blood leaves lungs via capillary
*Atrium contracts	
Valve opens	
Blood flows into ventricle	
Ventricle expands	
Heart muscle contracts	
Valve opens	
Blood pushed to upper body	
Blood pushed to lower body	
Valve closes	
Oxygenated blood into deoxygenated blood	
Deoxygenated blood flows in to right atrium	
*Atrium contracts	

- Number of translation dynamics and transformational dynamics on each animation.

	Circulation	**Respiration**
Translation	Deoxygenated blood Goes from upper & lower body into heart Flows from atrium into ventricle Flows out of heart to both lungs Oxygenated blood Flows from both lungs into heart Flows from atrium into ventricle Flows out of heart to upper and lower body	Grey cells entering capillary flowing through capillary and exiting the capillary Blue circles moving from capillary to alveolar sac Red circles moving from alveolar sac to capillary Red circles moving within sac Blue circles moving within sac
Transformation	Red cells change to blue in the upper and lower body Blue cells change to red in both lungs Valves open and close Atria contract and expand Ventricles contract and expand Change in speed of blood flows	Blue circles change from opaque to transparent Red circles change from transparent to opaque Grey circle loses a blue circle Grey circle gains a red circle
0Feature presence		Blue circle disappears Red circle appears

Table 5.2. Identification of salience and interpretation

- Salience of change may be affected by the following

1Circulation					
Graphical element	**Type of movement**	**Frequency of the motion**	**Duration of motion**	**Speed of motion**	**Relative magnitude of motion**
Blood	Translation Transformation	Constant Constant	High Short	Variable Fast	Large Small
Muscle	Transformation	Once	Medium	Medium	Medium
Valves	Transformation	Once	Short	Fast	Small
Respiration					
Blood cells	Translation Transformation	Constant Regular	Constant Regular	Medium Fast	Large Medium
Oxygen	Translation Transformation	Constant Regular	Constant Regular	Medium Fast	Medium Small
Carbon dioxide	Translation Transformation	Constant Regular	Constant Regular	Medium Fast	Medium Small

- Interpretative changes to be understood

Circulation	Respiration
Red cells to blue cells Blue cells to red cells Heart muscle contracting Valves opening and closing Heart chambers changing Blood cells moving	Blue circle leaving blood Red circle entering blood Blood cells moving Red circles appearing Blue circles disappearing

Chapter 6

Dynamic parsing: The effect of dynamics on salience and interpretation of graphical change; A case study.

6.1. Summary

The current chapter and chapter seven look at the process of cognitive interaction with animated diagrams, focusing on how and what learners see and interpret in terms of graphical change, and whether this is affected by complexity of the animation defined in terms of memory load due to transience and multidimensionality of the representation. These two sets of properties specific to animation have been identified in relation to the animations employed in this study, and a model of learning with an animated diagram in relation to these graphical properties is proposed (see chapter five). With these perspectives as a basis, an empirical case-study and an experimental study investigated the kinds of graphical change noticed, identified and the ways in which each of these changes were interpreted by pupils studying dynamic processes. To do this two animations were used both identified as being different in terms of their complexity to see if differences in processing could be attributable to animation complexity in terms of its memory overload. Processing aspects focused on here were issues concerned with visibility and parsability of dynamic change. This chapter, therefore, describes and analyses an empirical case study, which exemplifies ways in which some of the points raised about cognitive interaction with animation may be investigated. The results show evidence of patterns in cognitive processing, providing the basis for generating an initial cognitive model for processing graphical change.

6.2. Rationale and aims of studies

The primary aim of these studies was to investigate cognitive processing of graphical change in terms of the salience of the graphical change and the interpretability of those changes. Kaiser et al (1992) proposed that processing dynamics was easier where only one dimension of movement was displayed. Generally speaking an animation of a dynamic system will consist of more than one dimension of movement (simultaneous display of different kinds of movement), but research suggests that the more dimensions of movement the more cognitively complex the representation (Kaiser et al. 1992). Therefore, these studies also investigated the effect of complexity of the animation in terms of memory load due to multidimensionality of dynamics on this processing. By examining the learning process in relation to the properties of graphical change and multidimensional dynamics the aim is to identify and establish some components of a process model of cognitive interaction with animated graphical representation. To achieve this two separate studies were designed, *(i)* a case study using qualitative data (presented in this chapter) to exemplify the way in which the use of animation as a diagrammatic representation can be investigated in terms of the relationship between graphical properties and the learning process, and *(ii)* an experimental study (presented in chapter seven) using more rigorous methodology, which was completed to validate findings from the case study.

6.3. Method

6.3.1. Participants

Participants were fifty two pupils aged twelve and thirteen years. Twenty eight were male (mean age = 12 years 8 months; 152 months, sd = 3.4 months) and twenty four were female (mean age = 12 years 8 months; 152 months, sd = 3.6 months). All participants attended a Sussex comprehensive school where science classes were of mixed ability. Participants were assigned to work in pairs by their teacher on the basis of working well together. Each pair was assigned to one of the animations, complex (heart) or simple (respiration), and one of each pair was either an active (explainers) or a passive (listeners) learner.

6.3.2. Materials

(i) The animations (see appendix 8)

Establishing more clearly the benefits or disadvantages of learning using animation requires examination of the inherent dynamic property of animation, therefore, diagrams that depicted dynamic processes were selected. In this study the animations were analysed in terms of the properties identified above: memory overload and graphical change. Properties of the animations were identified in the following way (also see table 5.1): (i) The degree of memory overload was operationalised by the number of dynamic changes that occur in the animation. This comprised of: the number of moving parts, the number of directional movements, the number of locations of movement (to and from), the number of objects moving from one place to another, the number of sections demonstrating the process, and the number of simultaneous movements. (ii) Type of dynamic change was identified by the number of translation or transformational changes taking place. The distinction between types of graphical change (translation and transformation) allowed investigation into whether or not differences existed in processing these two types of information, both in terms of salience and in interpretation of the changes. To recap, translation change comprises movement from one location to another, transformational change comprises change in (object) form. In the heart animation an example of a translation change would be the depiction of blood flowing from the lungs into the heart. An example of transformational change would be red dots changing into blue dots in the body representing the change from oxygenated to deoxygenated blood (also see table 5.2.).

Two animations were used in this study in order to provide differences in complexity level of the animations in terms of memory overload and of graphical change. The animations used in this study were of blood flow through the heart and gas exchange in the lungs, and are described in detail in chapter five. The heart animation was categorised as 'complex', relative to the respiration animation which was categorised as 'simple', on the basis of the analysis described in chapter five. The animations were designed to appear on the screen initially in static format in order that the learner could familiarise themselves with the context of the diagram and the relevant component locations, and so that the researcher could explain relevant aspects of the diagram for understanding that were not specifically related to the dynamic aspects being investigated. The learner was then required to click anywhere on the diagram to begin the animation. The animation played for the pre-selected time (loop) determined on the basis of the pilot study. To play further loops the learner again was required to click anywhere on the diagram.

(ii) Task

Pupils were given a comparatively open task to preclude possibilities of priming for specific information which would compel pupils to focus on some aspects and ignore others. For the heart animation they were requested to find out about blood flow through the heart and body, and as much as they could about how the heart works:

> 'Use the animation to find out as much as you can about the process of blood flow and how the heart works'.

In the respiration animation they were requested to find out as much as they could about how gas exchange takes place in the lungs.

> 'Use the animation to find out as much as you can about the process of gas exchange during respiration'.

(iii) Outcome Measures

Learning outcomes were assessed in two ways: (i) by using data from video recordings taken of pupils explaining their understanding of the animation to one another at regular points throughout the learning session. Information was extracted by coding verbal data in relation to identifying and interpreting the dynamics on the animations, and (ii) with a written post-test completed individually by all participants, identifying specific dynamic information from the animations (see appendix 9). These aspects were related to cognitive processing through categorising questions in order to elicit information about the learning process as described above.

The post test consisted of a series of written questions with a mixture of multiple choice and open questions, according to the kind of information required. The test questions were designed and classified into the two relevant categories described above for acquiring information from the animations in terms of their complexity and the graphical changes. A small section of the test also targeted some overall conceptual understanding of the system. Thus, there were three categories of questions: (i) salience, which incorporated noticing both translation and transformational graphical changes; (ii) interpretation, which required the learner to suggest what each of the graphical changes was representing; and (iii) conceptual questions, which looked at evidence for a higher conceptual understanding of the process being learned (for categorisation see appendix 9b). The number of conceptual questions were minimal, as this was not the primary focus of the study. Open questions were used primarily for assessing interpretation of graphical change in order to elicit spontaneous descriptions, whereas salience of graphical change was assessed primarily through multiple choice questions. An example of a typical multiple choice question about salience required pupils to tick whether a statement about certain graphical changes was true or false. Typical questions eliciting information on interpretation required pupils to write the meaning of, for example, the blue dots changing to red. This enabled analysis of specific aspects of graphical change, both in correct perception, interpretation and inference, and in the kinds of errors made in each category. The aim of categorising the questions was to establish which kinds of graphical changes were noticed, or not, those changes that were interpreted, or not, whether any relationship existed between noticing and interpreting, and whether performance on one or both of these aspects influenced conceptual understanding. Video recordings of activity and collection of verbal protocols during the session gave additional information about the kinds of graphical change noticed and the interpretation placed on the graphical change, as well as difficulties pupils experienced in explaining aspects of the diagrams.

6.3.3. Design

A consequence of the proposed methodology, which required verbal protocols from pupils, meant that another aspect could be investigated in this study, that of learning mode in terms of active or passive learners. Working with pupils in this way is beneficial to the research, as not only does it provide rich verbal information, but also it is a familiar way of working for the pupils, and reassuring to work with a fellow pupils in a new situation. As a result one pupil became an explainer (classed as an 'active' learner) and the other a listener (classed as a 'passive' learner), with each completing separate test questions. This experiment was, therefore, a 2 x 2 independent measures design with a written post test to measure learning. Independent variables were complexity of animation and learning mode. Dependent variables were test scores on salience of graphical change, interpretation of graphical change, and conceptual understanding.

6.3.4. Procedure

Pupils worked with the animation in pairs. The researcher randomly selected one of them as explainer and one as listener. They were told that the explainer would be required to explain what they had seen and understood from the animation to their 'listener' peer. They were informed that they would view five separate runs of the animation, but between each run that the explainer would be required to describe to their partner what they had seen happen on the screen and what they thought this meant in terms of how the heart worked or how gas exchange occurred in the lungs. Pupils used the still frame left after each animation as a tool for their explanation, facilitating both gestural and verbal data. During the session, the researcher also prompted where necessary with statements such as, What did you see happen? What do you think this means? What do you think this is showing?

Before the animation began pupils were given an introduction to the diagram in static format. For the heart this entailed a verbal explanation from the researcher that the blue colour represented deoxygenated blood and the red colour represented oxygenated blood (this information was also in text form on the diagram), and an indication of the location of the body and lungs in relation to the heart. For the respiration animation this consisted of showing the location of the capillary and the alveolar sac, the relevance of the alveolar sac to the lung, and the representation of blue as carbon dioxide and red as oxygen (this information was also in text form on the diagram). Both animations were run on an Apple Macintosh Powerbook in a classroom at the school. All sessions were openly video recorded. At the beginning of the session all pupils were also informed of the requirement to complete a written post test questionnaire at the end of the session. After completion of the test pupils were shown a continuous version of the animation and the process depicted was explained to them by the researcher.

6.3.5. Pilot study

A pilot study was conducted with six pairs of pupils to establish important criteria for working with the animation. Each of the animations were cyclical and could therefore be looped. Thus, it was important to establish an appropriate number of runs or loops of animation to enable understanding of the domain, but guarding against the possibility of all pupils understanding everything due to seeing many runs of the animation. It was determined that five runs (94 frames at 15 fps, approx. 8 seconds running time) of the heart animation and four runs (55 frames at 8 fps, 8 seconds running time) of the respiration animation used here were sufficient for the purposes of this experiment. The suitability of the wording and design of the test questionnaire for the target age group was also established, as was the feasibility of pupils watching an animation and explaining what they saw and understood to a peer. Some questions on the test were altered or reworded to improve clarity of the test. It was clearly established that pupils were able and willing to explain the diagram to their partners, thus enabling verbal protocol data as well as written data, providing more comprehensive information on the learning taking place.

6.4. Results

Data was obtained through post-test scores, verbal protocols, and video analysis. The results are reported here in two parts; *(i)* quantitative analysis of performance according to overall test scores, different question categories, complexity of animation, and learning mode; and *(ii)* qualitative data taken from video recordings and verbal protocols. In order to analyse graphical change coding of the different kinds of change was required.

- Graphical change coding.

Translation refers to graphical change that is a movement of an object or item from one place to another. Transformation refers to graphical change that involves the object transforming in some way, be it shape, size, colour, identity etc… Unsurprisingly, there are occasions when the distinction between translation and transformation may be blurred when the gross movement involves both of these transitions. In these cases coding was done according to the reference of the pupil, whether they referred to the translating object or the transforming object. For example in the respiration animation a grey circle (representing blood cells) travelling along the capillary has components inside it, one of which is a blue circle representing carbon dioxide. The blue circle or carbon dioxide moves from the grey circle in the capillary across a membrane into the alveolar sac. The movement of the blue circle across the membrane would be coded as translation, whereas reference to the change in the grey circle would be coded as transformational. Thus, a description such as "the blue circle went into the sac" would be coded as a translation change, whereas a description such as, "as the capillary passed, oxygen went in and carbon dioxide was taken out" or "red oxygen goes into grey circles and blue circles get put back" would be coded as a transformation change. Here the reference is to the change that is occurring in the grey cells rather than the movement of a circle from one place to another.

6.4.1. Quantitative analysis

The tests were divided into three categories for analysis. Due to differences in domain and complexity of animation the heart and respiration tests differed in number of questions. The total possible scores for the heart animation were: total test score – 32; salience category – 19; interpretation category – 7; conceptual category – 6. The total possible scores for the respiration animation were as follows: total test score – 22; salience – 9; interpretation – 6; conceptual – 7. All scores were transformed and computed into percentages prior to analysis in order to standardise the scores for comparison.

(i) Performance according to complexity of animation and learning mode

This analysis looked for differences in test scores between active and passive learners according to animation used (complex or simple).

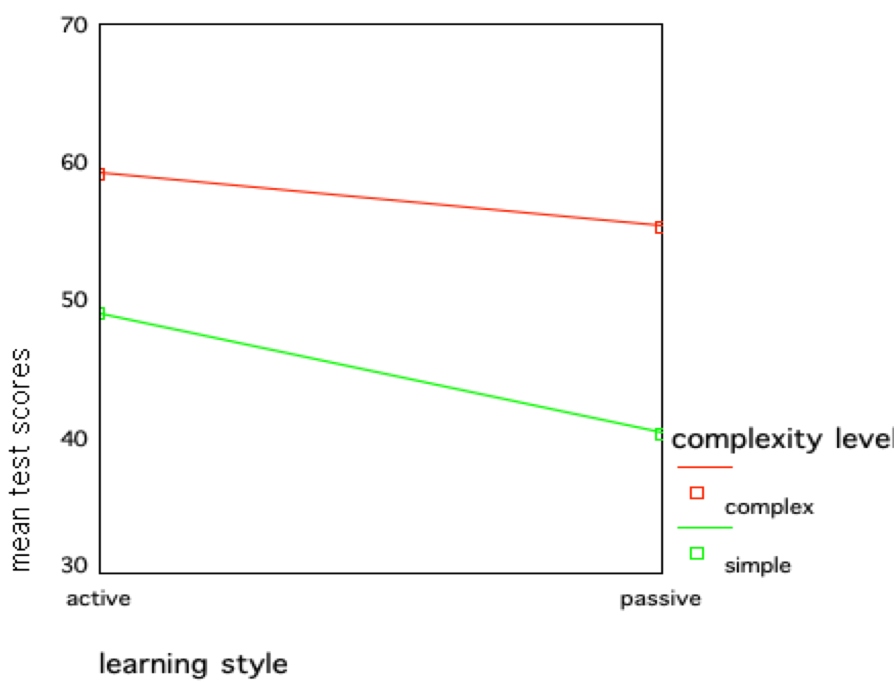
The means and standard deviations of the test scores are given in table 6.1.

Table 6.1. Mean test scores for complexity of animation and learning mode

Complexity level	learning style	Mean	Std. Deviation	N
complex	active	59.13	10.70	13
	passive	55.28	20.30	13
	Total	57.21	16.02	26
simple	active	48.95	18.00	13
	passive	40.20	21.86	13
	Total	44.58	20.12	26
Total	active	54.04	15.41	26
	passive	47.74	22.05	26
	Total	50.89	19.10	52

A two way independent analysis of variance (ANOVA) was performed on the overall test scores. There was a significant main effect of complexity of animation ($p=0.01$). Those using the complex animation performed significantly better overall on the test than those using the simple animation. No significant effect of learning mode was found (see figure 6.1.). Overall active and passive learners scored similarly on the test.

Figure 6.1. Graph showing main effects of complexity of animation and learning mode



(ii) Differences in performance according to question category and complexity of animation and learning mode.

A MANOVA was used to assess differences within question categories according to complexity of animation and learning mode (see table 6.2. for mean scores).

Table 6.2. Means of scores in different question categories according to complexity level and learning mode

	complexity level	learning style	mean	standard deviation	N
Salience	complex	active	68.01	8.44	13
		passive	65.18	19.87	13
		total	66.59	15.03	26
	simple	active	63.24	24.58	13
		passive	62.39	24.23	13
		total	62.82	23.92	26
	total	active	65.63	18.17	26
		passive	63.78	21.75	26
		total	64.70	19.87	52
Interpretation	complex	active	53.84	19.47	13
		passive	46.15	19.47	13
		total	50.00	19.48	26
	simple	active	56.41	27.67	13
		passive	34.61	32.24	13
		total	45.51	31.46	26
	total	active	55.12	23.48	26
		passive	40.38	26.75	26
		total	47.75	26.01	52
Conceptual	complex	active	37.17	30.54	13
		passive	34.61	36.29	13
		total	35.89	32.89	26
	simple	active	24.17	18.79	13
		passive	16.48	20.90	13
		total	20.32	19.86	26
	total	active	30.67	25.71	26
		passive	25.54	30.45	26
		total	28.11	28.02	52

The analysis showed a significant difference within the interpretation category ($p = 0.04$), showing that active learners performed better on interpretation of graphical change than passive learners. The analysis also showed significant differences in the conceptual category ($p = 0.04$) showing that those using the complex animation scored higher on conceptual questions than those using the simple animation.

(iii) Performance on different question categories

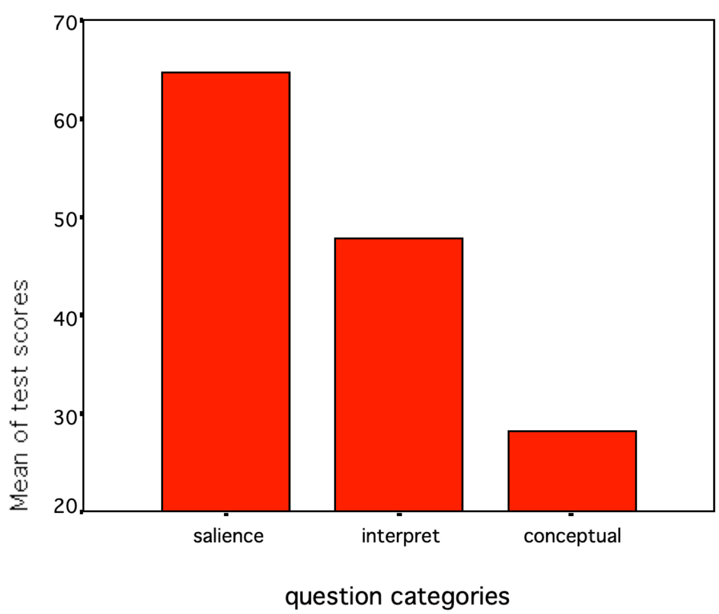
A repeated measures ANOVA showed significant differences between scores on the separate question categories ($p = 0.00$). The means (table 6.3.) suggest that, overall, higher scores were obtained for salience questions than for either interpretation or conceptual questions regardless of complexity of animation or of learning mode.

Table 6.3. Overall mean scores obtained for each question category

	mean	standard deviation	N
salience	64.70	19.87	52
interpretation	47.75	26.01	52
conceptual	28.11	28.02	52

A polynomial contrast showed a significant linear trend. Thus, performance on the salience questions was significantly better than on the interpretation questions, and performance on interpretation was significantly better than on conceptual questions (see graph 6.2.).

Figure 6.2. Overall means of performance on question categories



(iv) Analysis of errors made

Detailed examination of individual questions within each question category, was undertaken to find out whether there were any patterns of responses within each category. This was done by focusing on both accurate responses and the types of errors made. Thus, each of the question categories was inspected in terms of which individual questions were correctly answered 80% of the time, or more, and which questions were poorly answered to find out more specifically which dynamics were or were not noticed, which were or were not interpreted.

Overall, pupils scored well on most aspects categorised as salience and the majority of the graphical changes were accurately noticed. However, some questions showed consistent errors, primarily in recall of identifying translation graphical change. Accurate interpretation of graphical change primarily occurred in relation to transformational changes. All scores in the conceptual questions category, regardless of animation, were low.

6.4.2. Qualitative analysis

Information was collected from video recordings of pupils working with the animations. This comprised verbal and gestural data, both explaining and pointing out aspects on the diagram to their peer after each run of the animation. Analysis of video recordings and verbal protocol data comprised coding of particular aspects to look at identification and interpretation of graphical change, patterns of information acquisition and kinds of errors made. The most noteworthy of these aspects was in relation to perceiving and understanding translation and transformational differences in graphical change. (For detailed coding of graphical change see 6.4.1.)

(i) salience

Patterns of identification of dynamics according to translation and transformation change were evident. After one run of the animation, the number of translation dynamics noticed or commented on were notably higher than the number of transformational dynamics in both animation conditions (i.e. the total number of translation dynamics noted was 45, whereas the total number of transformations noted was 12). After a further run of the animation this difference was apparent only in the respiration animation, but after more runs the number of each type of change was similar. Thus, the differences between the two kinds of graphical change were most distinctive in the early stages of using the diagrams. The implications of this in relation to processing dynamics is discussed below.

(ii) Interpretation

Generally, on the respiration animation pupils were unable to accurately interpret the graphical change, unlike the heart animation where fairly good interpretations were made. Three questions from the heart animation were identified as receiving a ‘high’ number of correct answers. These were that the blue dots changed to red dots, the red dots changed to blue dots, and the heart muscle got thinner and thicker. These answers suggest that the change of blood from oxygenated to deoxygenated and vice versa was understood correctly, and the cardiac muscle action. However, poor interpretation was achieved for alteration in speed of blood flow and different graphical changes of the ventricles.

6.5. Discussion

The focus of the discussion, from the results presented here, is on the information gleaned from both the test questions and from the variability of processing noted after each run of the animation from video data, the aim being to identify cognitive components of a processing model of animation. To do this information was collated that related specifically to learning through dynamics of the representation. The dynamics of the diagram were identified as particular types of graphical change (transformation and translation), and the kinds of learning were specifically identified in relation to perceiving and understanding of graphical change (salience and interpretation). The aim of categorising the questions was to establish which kinds of graphical changes were noticed, or not, those changes that were interpreted, or not, whether any relationship existed between noticing and interpreting, and whether performance on one or both of these aspects influenced conceptual understanding. Understanding animation is a gradual process of acquiring and integrating pieces of information, but what are the components of this process? Using data from the perspective of the learning process (question categories) and of graphical representation (type of graphical change), the results from this study point to possible cognitive components of processing information using animation.

6.5.1. Main effects of complexity of animation and learning mode

This section discusses the implications of complexity of animation and learning mode for using animated diagrams of dynamic processes.

(i) Complexity of animation

The test results showed that overall those using the complex animation performed significantly better than those using the simple animation. Further analysis showed that this was significant for the conceptual category of questions. These results were not expected, but could be explained by higher prior knowledge in pupils working in the domain of the heart. It transpired that science coursework at the time of data collection included instruction in class on the heart, but no pupils had received any teaching on respiration. It was therefore likely that this affected the kind of processing that is required for reading an animated representation. Previous research has shown that there are differences in the way information is perceived and understood according to the level of expertise of the learner/user, due to the effect of their internal representations on the way they interact with the diagram (e.g. De Groot 1965, Egan and Schwartz 1979, Lowe 1994, Satchwell 1996, Brna et. al. 1997). This domain knowledge acquired by participants using the heart animation may have meant that the learner was not necessarily required to rely on salience and interpretation of graphical change to the same degree as those with less domain knowledge, in order to have conceptual understanding. It may also have lessened the detrimental effect of some properties of the representation, such as transience and multidimensional dynamics (see 6.5.2. for these effects).

(ii) Learning mode

The test results showed that active learners interpreted graphical change significantly better than passive learners. This could be a result of the active learners having to explain the representation to their peer and in so doing, externalise their reasoning. This gave the opportunity for them to discover what they understood and what they did not, clarifying which aspects of the representation they needed to focus on more. This correlates with Chi's (1997) self explanation model. Explaining may have the effect of prompting not only more cognitive effort, but also more appropriate cognitive effort through identifying errors and mismatches in their explanations.

6.5.2. Differences in knowledge acquisition according to graphical change

From the test score means it was evident that scores in the salience category were superior to scores in the interpretation category, and scores on interpretation were superior to those in the conceptual category. Higher scores in the salience category may suggest two things: *(i)* that identifying salient dynamic aspects are processed before interpretation of those aspects; *(ii)* that salient aspects of graphical change were less cognitively demanding for learners than interpretation. Higher scores in the interpretation category may suggest that interpreting the graphical change is an important part of identifying relevant information that serves as a pre-requisite for conceptual understanding. This progression points towards the beginnings of a cognitive model for processing graphical change in that seeing an event happen occurs before interpreting the meaning of the event, which occurs before the individual meanings are combined to make a coherent understanding of the process. However, other aspects of graphical change are also relevant to a proposed processing model. Data collected from verbal protocols and video recordings, also revealed pertinent differences in processing.

(i) Salience

Differences relating to the morphological properties of the animation (salience) according to type of graphical change were apparent. In the early stages of animation viewing translation change was primarily identified. In both animations, after one run of the animation, more translation than transformational changes were identified. This suggests that translation change may initially be more prominent than transformation. There was also a high degree of uniformity in the actual translations on which pupils focused. For example, translations in the heart focused primarily on deoxygenated blood going out of the heart and the oxygenated blood flowing in. Translations noted in the respiration animation consistently focused on the blue circle moving from the capillary to the alveolar sac and the red circle moving from the alveolar sac to the capillary. This might suggest that certain areas of the diagram are more initially prominent than others.

As viewing increased, the number of both transformational and translation changes identified were more evenly distributed, although the pattern differed according to animation. In further runs of the heart animation the number of transformations noted gradually increased. Initially these transformations focused on changes in size or behaviour (e.g. ventricle and valve movement) rather than changes in colour (e.g. red dots to blue dots). However, by three runs of the heart animation pupils were beginning to notice dots changing colour (representing blood change). This pattern may be a result of the fact that transformation involving change in size shows a gross motion change, whereas a change in colour is a more subtle superficial change. This may cause some transformations to be more salient than others, but, the results suggest that, as more interaction with the animation occurs, additional kinds of graphical change can be attended to and assimilated.

In contrast, in the respiration animation, translation change was identified more frequently after each run, than transformational. Few pupils identified transformational change, and only one pupil *accurately* perceived transformational change. For example, the blue circles (carbon dioxide) were falsely noticed to change into red circles (oxygen). This evidence also suggests that translation change is identified prior to transformational change. However, identification may not necessarily be accurate, which has additional adverse effects on the quality of the translation of the graphical change.

(ii) Interpretation

When it comes to understanding the semantic properties of graphical change (interpretation) the story is more complicated. Although, on the whole, interpretation given was minimal, on one hand there is evidence for some graphical change being interpreted more easily (or perhaps readily) than others, but on the other hand, the same graphical change results in multiple errors. Initially it appears that translation changes are more easily interpreted than transformation changes, as more ready interpretations were made for this kind of change. One reason for this could be that interpretation, in this instance, is combined with the identification of the movement. For example, from verbal protocols translation change was generally described in the following way, (it) 'comes in here and goes out there' accompanied by pointing. However, errors evident from test data suggest that translation change is not necessarily more easily interpreted than transformation. Although some blood pathways were correctly perceived, others were not, and pupil answers demonstrated that a mixture of accurate and inaccurate perceptions of blood flow were held. For example, pupils perceived both red (oxygenated blood) and blue dots (deoxygenated blood) going to the lungs from the heart; both red and blue dots entering the heart from the body; and both red and blue dots entering the heart from the lungs, when in actuality only one type of blood follows each of these pathways. The same confused pattern of movement in terms of blood flow pathways was apparent from the conceptual questions relating to locations of flow of different kinds of blood. This also suggests that the blood flow pathway is not clear and the translation dynamics are confusing, and result in an incoherent pattern of understanding blood flow pathways. This may suggest that;

(i) Although the form of translation movement may render it more easily perceived initially, the understanding or the interpretation of this kind of movement does not necessarily follow the same principle. Therefore, in processing animated information ease of perception does not guarantee ease of interpretation or understanding.

(ii) Confusion of translation movement was apparent in the 'complex' animation rather than the 'simple' animation, which suggests that the difficulty of fully perceiving or of interpreting translation may lie in the multidimensionality of the graphical change, rather than the graphical change per se. The level of information load resulting from multidimensionality may increase the number of potential dynamic distractions for the learner.

(iii) The problem of the transient nature of animation is apparent, in that information is lost between viewing the start and end of the translation movement, precluding pupils from fully identifying the change occurring.

(iv) That despite increased exposure to the animation pupil integration of what they saw and what they understood as a whole was not taking place.

Interpretation of transformation was minimal, and forced more errors in the respiration animation than on the heart animation. This could have been due to differences in prior knowledge, facilitating focus of attention, kinds of changes or processes taking place. This suggests that when there is less prior knowledge then interaction with the animation may need to be radically different from when a higher level of prior knowledge exists. Interpretation of representations has been found to be affected by prior knowledge (and expertise with the representation) (Brna 1996). Errors on the heart animation could be equated to lack of perception of those changes. Several pupils had not noticed these changes occurring during the animation, so would be unable to map the action to any meaning. Transformation interpretation also forced more errors than interpretation of translation change on the respiration animation. For example, the carbon dioxide was falsely perceived to change into oxygen in the capillary.

Few interpretations given, and inaccuracy in those made, could suggest the following;
(i) identifying a change may be a prerequisite to interpreting the change.
(ii) generally, making interpretations at an early stage of processing the dynamic information may be problematical.
(iii) making interpretation of transformation changes requires a further step in cognitive processing than translation changes, as the interpretation of what is happening when an object moves from one place to another is integral to the dynamics themselves, whereas a transformation is representing something more than a change in location and requires identification of the change (e.g. change in colour, change in size, change in shape) and placing some coherent meaning on the change depicted.
(iv) translation changes become more difficult to interpret as the number of similar translation changes increases.
(v) identifying the change as translation, transformation or feature presence affects the kind of interpretation made. Therefore clarity of the kind of movement or change is essential in facilitating accurate interpretation.

Responses to the conceptual category were generally unsatisfactory. This could be because conceptual understanding is harder to achieve anyway; better interpretation of graphical change may be necessary before a higher level of understanding is reached; better interpretation or longer spent working with the animation may have enabled improved integration of information and the inferences necessary to achieve better conceptual understanding; the problem of hidden processes was evident when the pupils were working with the animations. For example, the relevant or accurate links between peripheral processes relating to respiration and circulation were not at all apparent from pupils reports.

6.5.3. Further errors in learning

As seen above analysing errors in pupils learning provides information that contributes towards a cognitive model of processing animation. Two further errors evident from the respiration animation are noteworthy. Poor scoring was obtained for the salience of the events of the blue circle (carbon dioxide). The category most selected about the blue circle was the one that stated that the blue circle changes to a red circle (thirteen of seventeen wrong answers). Verbal protocol data is consistent with this, indicating that a high proportion of pupils thought that the blue circle changed into a red circle rather than identifying the blue circle (carbon dioxide) moving out and the red circle (oxygen) moving in, in separate actions**.** This error might lead to misinterpreting that carbon dioxide is changed into oxygen rather than carbon dioxide being removed and oxygen being absorbed. If this is the case then the process of diffusion is unlikely to be attended to as the only process being perceived is a false exchange process. In terms of a processing model this suggests that:

(i) each step in the perception, or identification, of and interpretation of graphical change can have significant effects on understanding, and

(ii) that a misidentification of change being a transformation as oppose to a translation will effect the kind of interpretation placed on the meaning of the representation.

Another frequent error made in the respiration animation was the misperception of the blue circle disappearing and the red circle appearing in the alveolar sac. This may be because this kind of graphical change is more difficult to perceive. The form of this graphical change is different from the explicit motion intrinsic in translation and explicit visual alteration in transformation changes, and may not, therefore, attract attention. This type of change might be described as an addition and/or subtraction of a graphical element. The change specifies whether a particular graphical feature is present or not present (“feature presence”), but its appearance or disappearance is not obvious in any way. ‘Feature presence’ might explain the lack of ‘noticing’ of these events, which may need to be accompanied by other means of attracting attention, such as highlighting or sound.

6.5.4. Summary of discussion

From this study several points have emerged that are relevant to cognitive interaction with graphical animation. The emergence of another type of graphical change, termed here ‘feature presence’, is a change which turns out to be difficult to perceive, and therefore has a tendency to go unnoticed. This is an important factor in designing animation and/ or guiding learners using this form of representation. There is evidence that different types of graphical change are processed differently in terms of salience and interpretation. This may be important in understanding how learning may be guided and/or shaped according to the design and use of these graphical changes. More importantly, the study provides information towards a preliminary description of a cognitive model for processing graphical change.

6.6. Contribution to cognitive model of processing

The results from this study suggest certain stages in processing graphical change from animated diagrams of dynamic processes, which will be related to the cognitive demands of ‘reading’ graphical change.

6.6.1. Visibility demands

The above study suggests that processing of graphical change consists of not only of visibility in terms of noticing the changes taking place, but also the identification of the kinds of graphical changes taking place.

(i) noticing graphical change

The salience of this may be dependent on the type of graphical change. Translation appears to be initially noticed more readily than transformation, whereas feature presence appears to be problematic to notice. However, ease of perception does not necessarily guarantee ease of identification or interpretation. Thorough noticing of graphical change may, however, be affected by the multidimensionality of the animation (the more changes occurring the more difficult it is to notice accurately) and by the transient nature of the representation, which contributes to potential loss of information from the start to the end of a translation. These interferences in cognition may also apply to transformation changes.

(ii) identification of graphical change

Accurate identification of the type of graphical change is imperative to coherent interpretation of the representation. Whether the graphical change is seen as transformation, translation or feature presence will affect the interpretation made.

6.6.2. Interpretative demands

Interpretation of graphical change

Accurate interpretation is necessary for a coherent understanding of the system or process depicted, but making interpretations at an early stage of processing dynamic information can be problematical. The interpretation that is placed on the graphical change is dependent on the type of change that is perceived and identified, and on the extent to which the change observed. For example, understanding will be incomplete if only part of a translation change is viewed. It is also apparent that making interpretation of transformation changes requires a further step in cognitive processing than translation change, as the interpretation of what is happening when an object moves from one place to another is integral to the dynamics themselves, whereas a transformation is representing something more than a change in location and requires identification of the change (e.g. change in colour, change in size, change in shape) and placing some coherent meaning on the change depicted.

It can be seen from these findings that visibility, in terms of clarity of graphical change taking place and the kind of change that occurs, is important in providing a good basis for reading animation. However, it is also clear that for animated diagrams there is another dimension - that of interpretability – that is fundamental to coherent understanding of animation. So not only is visibility important, but also interpretability (of the dynamic change) in the readability of the diagram.

6.7. Limitations of study

During data collection and analysis several limitations of the experimental design, and alternative ways of examining proposed issues within this study became apparent, as well as limitations on the conclusions drawn. As the majority of these issues are also shared by the following experimental study, these limitations will be discussed in full in chapter seven (see 7.5.). However, one particular aspect emerged suggesting that modification of categorisation of test questions was required. Examination of the results indicates that there are differences in processing according to the type of graphical change (tranlsation or transformation). On the basis of this it became apparent that some questions relating to the heart animation that were originally designed to elicit conceptual knowledge actually targeted the accuracy of interpretation of translation change (blood flow pathways). Although this generally highlights the difficulties in designing questions for assessment, it is essential that the questions be categorised in the most appropriate way for the issues being investigated. The test questions were, therefore, re-categorised for the following experimental study (Study 4, see 7.2.2.).

6.8. Conclusion

This chapter focused on specific properties of dynamic graphical representation, and on particular aspects of learning with animation, to investigate the feasibility of bringing to light information about the cognitive processing of animated diagrams. The first part of the chapter highlighted particular properties of animation that could be used to identify certain cognitive processes, and identified particular learning aspects that are pertinent to the processing of dynamic information. The second part of the chapter described an empirical case-study investigating aspects of learning with animated diagrams, the results of which can be used for an initial description of the early stages of processing dynamics from animated diagrams. However, there are limitations to conclusions which can be drawn from a case-study in terms of the number of participants and the methodology, for example, discretion must be taken in making inferences from comparisons of processing with two different animations in terms of, for example, equivalent complexity in test questions. The same study was, therefore, carried out using different subjects under more rigorous experimental conditions, which enabled progression of processing to be examined within each domain animation. The following chapter describes this experimental study.

Chapter 7

Dynamic parsing: The effect of dynamics on salience and interpretation of graphical change; An experimental study.

7.1. Summary

Chapter six presented a case study investigating the effect of dynamics on the salience and interpretation of graphical change accounting for complexity of the representation in terms of its properties of transience and multidimensionality. This chapter presents an experimental version of the case study providing more rigorous experimental evidence for a cognitive process model of reading animation. A brief introduction will summarise the relevant details of animation properties and learning aspects appropriate for this study (for a more comprehensive description see chapter three and chapter 6.2.) The methodology was modified in line with an experimental design, consisting of three levels of viewing the animation (amount of exposure according to number of runs), in order to establish differences, or not, in cognitive processing of graphical change with more exposure to animation. The results of the study enable discussion on cognitive processing at each exposure level according to complexity of animation, processing of graphical change, as well as differences in cognitive processing across all exposure levels.

7.2. Introduction

This experiment set out to find out more specifically the cognitive steps involved in processing graphical change from an animation. This chapter begins by summarising the relevant cognitive properties of animation and the principles behind the outcome measures used, as explained and described in full detail in the previous chapter. The chapter then introduces the rationale behind the design and method of an experimental study, which clarifies some of the points raised about cognitive interaction with animation from the case study in the previous chapter. This study continues to focus specifically on dynamic aspects of the representation, linked with cognitive factors identified as important for processing dynamic information.

As in the case study, the cognitive properties of animation pertinent to this experiment were those relating to complexity of the representation (due to transience, multidimensionality) and graphical change. In terms of dynamics these features of animation all contribute to memory overload, which can be identified according to the quantity of changes, both the same and different, both occurring individually or simultaneously, that are depicted via the animation to accurately illustrate the depicted process. Graphical change can be further identified in terms of the form or kind of change, namely translation, transformation and feature presence. In chapter three a learning process model was proposed, suggesting that in order to understand dynamics using animated graphics each graphical change needs to be noticed (awareness that a change is taking place), identified (appreciation of the details of this change) and interpreted (placing appropriate meaning of the change in the context of the diagram) accurately within the context of the represented system. These pieces of information then have to be integrated coherently to begin to understand the entire concept depicted. By using the data sets across three different exposure times we can investigate whether any progression in learning occurs in terms of identifying and interpreting graphical change (a core feature of animation), and whether or not this is affected by the complexity of the animation depiction itself.

The previous chapter explicated a case study, whereas this experiment investigated, under more controlled conditions, the stages involved in ‘reading’ dynamics from an animated diagram. To do this the animations, as used in the case study, were presented to pupils in different multiples of short sequences of the diagram, e.g. pupils using the heart animation viewed either one, three or five pre-defined runs of the animation. For all experimental conditions apparatus was the same, instructions given to participants were identical, questionnaires were designed to provide more systematic assessment of the stages of cognitive processing of graphical change. All pupils were then required to complete the same questionnaire regardless of the amount of exposure to the animation. The aim of this was to gain specific information about which aspects of the diagram were attended to, identified, interpreted and at what stage of viewing the animation.

The hypothesis here was that the more times the animation was viewed the greater the amount of information seen, interpreted and understood. The results of this study will be reported and discussed in three separate sections: section one will cover the overall results for each separate condition of the experiment in terms of complexity of animation and processing of graphical change; section two will use the combined data to look at the differences in processing according to exposure to animation, comparing learning or processing from minimum to maximum exposure; and section three will look at errors in learning that may contribute to description of a model of processing graphical change.

7.3. Experimental study

7.3.1 Method

Seventy two pupils aged twelve and thirteen years from year eight of a Sussex comprehensive school participated in this experiment. There were 23 females (mean age = 12 years 10 months; 154 months, sd = 5.3 months) and 49 males (mean age = 12 years 11 months; 155 months, sd = 5.7 months). All pupils in the mixed ability classes participated providing a wide range of abilities. No pupils had taken part in the previous studies. Pupils worked with their allocated animation on an individual basis. No verbal protocols or explanations were required in this study.

7.3.2. Materials

(i) Animations

The animations used in this study were identical to those used in the case study (see 6.3.2. and appendix 8). The animations were designed such that they had a fixed looping or running time, and could be restarted by the participant pressing any button on the keyboard.

(ii) Task

Tasks given to pupils were identical to those given in the case study (also see 6.3.2.). Pupils were again given a comparatively open task to preclude possibilities of priming for specific information, which would compel pupils to focus on some aspects and ignore others. For the heart animation they were requested to find out about blood flow through the heart and body, and as much as they could about how the heart works. For the respiration animation they were requested to find out as much as they could about how gas exchange takes place in the lungs.

(iii) Outcome measures

Learning in this study was assessed via a written questionnaire consisting of multiple choice and open questions (see appendix 10(i) for heart and appendix 10(ii) for respiration). Questionnaires were completed individually by pupils immediately after viewing the animation. Some open test questions from the case study were modified into multiple choice questions for this study, as multiple choice questions were found to be more reliable in terms of scoring and, therefore, more reliable for making comparisons across groups. Open questions remained for interpretation of graphical change in order to elicit descriptions. Questions were again categorised according to relevant themes in terms of the identified learning process: salience (which targeted noticing and identifying graphical change), interpretation (which targeted the meaning placed on the graphical change) and conceptual understanding (also see 6.3.2.). Categorisation of some of the heart questions was slightly modified on the basis of results from the case study, which indicated that a more precise categorisation of questions eliciting knowledge about blood flow pathways would be interpretation of translation change (see appendix 10b). Whilst completing the test pupils were provided with a black and white static diagram of the main outline of their depicted animation together with relevant labels. This enabled them to understand more easily what certain questions referred to, so that the focus of the assessment could remain on salience and interpretation of graphical change rather than on the static components of the diagram (see appendix 11(i) for heart and appendix 11(ii) for respiration). Neither pre tests nor delayed post tests were implemented in this experiment as the focus of the assessment was to establish understanding of graphical change within the depicted domains. This requires accessing processing that is occurring at the time of 'reading' and involves information that is only appropriately available either during or immediately after participation.

7.3.3. Design

This experiment comprised two animations (complex and simple) and three different levels of exposure to each of the animations (minimum exposure, intermediate exposure, maximum exposure). Pupils were allocated to either the minimum, intermediate or maximum exposure, and used either the complex animation or the simple animation. Thus, it was a 2 x 3 independent measures design, with the test scores as the dependent variables. All participants worked on an individual basis.

7.3.4. Procedure

Pupils viewed the respective animation in pairs for the required number of times as allocated. They were not allowed to discuss between them what they had viewed and communicated only to agree when to run the animation for a second or third etc… time. They were informed of the number of runs of the animation they were required to view. Before the animation began pupils were given an introduction to the diagram in static format. This part of the procedure was identical to the case study (also see 6.3.4.). Again, for the heart this entailed an explanation that the blue colour represented deoxygenated blood and the red colour represented oxygenated blood (also in text on the diagram), and an indication of the location of the body and lungs in relation to the heart. For the respiration animation this consisted of showing the location of the capillary and the alveolar sac, the relevance of the alveolar sac to the lung, and the representation of blue as carbon dioxide and red as oxygen (also in text on the diagram). Both animations were run on an Apple Macintosh Powerbook in a classroom at the school. Pupils then completed the questionnaire independently, before returning to their classroom.

7.3.5. Pilot study

A pilot study was undertaken prior to the main study to establish an appropriate running time for each viewing, as well as an appropriate maximum number of runs for each animation for adequate comprehension, and to ensure ceiling effects would not be obtained. It was established for the complex animation that five runs was an appropriate maximum exposure, thus the one run was used for the minimum exposure and three runs were used for the intermediate exposure. For the simple animation it was established that four runs was an appropriate maximum exposure, thus one run was used for minimum exposure and two runs for intermediate exposure. The pilot study also confirmed the suitability of the test used, and any ambiguous wording was altered accordingly.

7.4. Results

The data collected from this experiment were primarily quantitative data obtained from test scores. The test was divided into three different categories according to type of question asked; salience, interpretation and conceptual. Thus, the final data consisted of overall test scores, and scores for each of the different categories. Total possible test scores for the heart animation were as follows: total test score – 46; salience – 25; interpretation – 7; conceptual – 14. The total possible test scores for respiration animation were as follows: total test score – 24; salience – 9; interpretation – 6; conceptual – 9. All scores were transformed and computed into percentages to enable comparison across groups. The different exposures of animation provided the facility for several different analyses. The results will, therefore, be presented in three sections; firstly, results for each animation exposure separately (minimum, intermediate and maximum exposure); secondly, comparisons across all animation exposure levels; and thirdly, errors in learning giving more specific differences in processing. As the focus of this study was primarily on salience and interpretation of graphical change, and the conceptual aspects elicited were minimal, the subsequent discussion will focus on results relating to understanding graphical change.

7.4.1. Results of each separate exposure condition

The results reported here investigated differences in test scores between complex and simple animations, both total test scores and individual question category scores. Analysis of each exposure condition will be presented separately.

(i) Minimum exposure

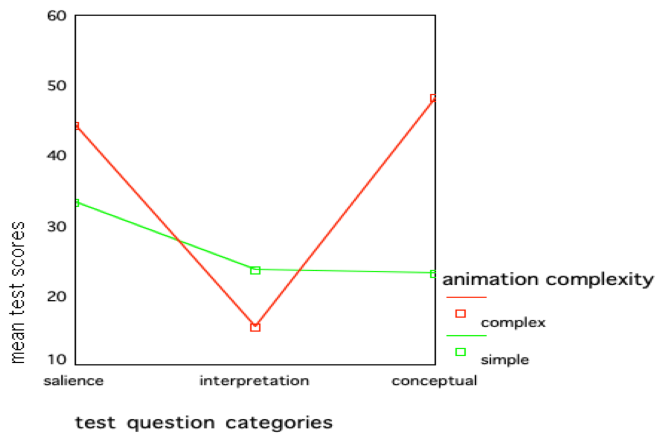
A MANOVA was performed to investigate the interaction of the question categories, with complexity as the independent variable and question categories are three dependent variables.

Table 7.1. Showing the mean scores for complexity and question categories in the minimum exposure condition.

Question category	Complexity	Mean	Std. Deviation	N
Salience	complex	44.33	11.37	12
	simple	33.33	15.71	12
	Total	38.83	14.54	24
Interpretation	complex	15.47	23.94	12
	simple	23.61	29.69	12
	Total	19.54	26.70	24
Conceptual	complex	48.21	19.53	12
	simple	23.14	16.03	12
	Total	35.68	21.66	24

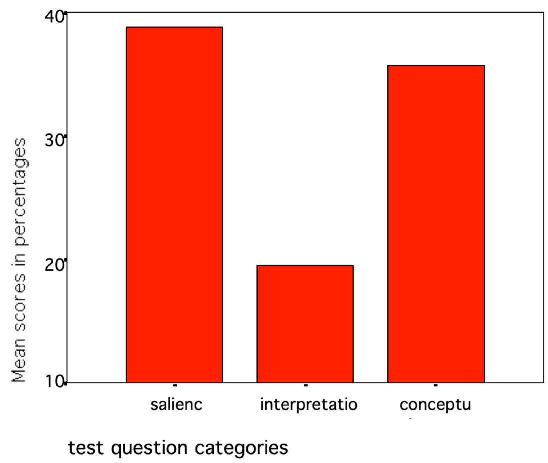
The analysis showed that performance significantly differed according to complexity of the animation (p=0.01). The test of between subject effects showed that these differences were significant in the conceptual category (p=0.00) and approaching significance for the salience category (p=0.06). In both of these categories those using the complex (heart) animation performed better than those using the respiration animation.

Figure 7.1**.** Graph showing the effect of animation complexity on performance after minimum exposure to animation



The MANOVA also showed significant differences in overall performance on the different question categories (p=0.00). Salience and conceptual questions were answered better than interpretation. A mixed ANOVA comparing the effects of complexity on the different question categories confirmed these findings. The independent variables were complexity (simple and complex) as a between subject factor and question category as a repeated measures variable with three levels (salience, interpretation and conceptual). A repeated contrast showed a significant difference between salience and interpretation categories (p=0.00) and between interpretation and conceptual categories (p=0.02). Overall pupils scored higher in the salience category than interpretation and higher in the conceptual category than interpretation.

Figure 7.2. Graph to show the effect of minimum animation exposure on processing of different types of information.



(ii) Intermediate exposure

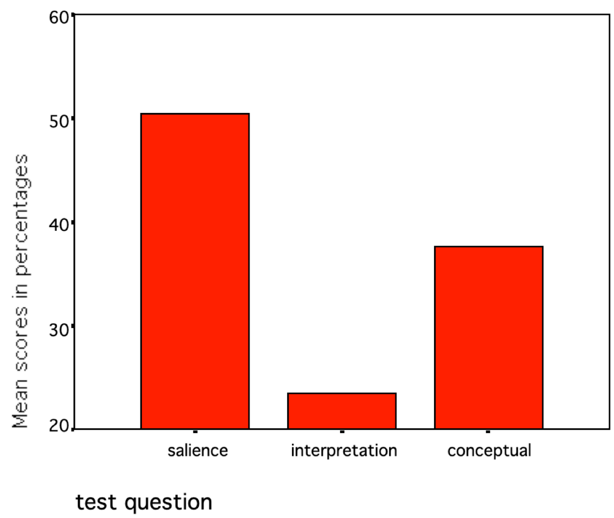
A MANOVA was performed to analyse the effects of the independent variable (complexity of animation) on the dependent measures (salience, interpretation and conceptual) and look for any interactions (see table 7.2. for mean scores).

Table 7.2. Showing mean scores for complexity and question category in the intermediate exposure condition

	Complexity	Mean	Std. Deviation	N
Salience	complex	52.66	17.37	12
	simple	48.14	15.94	12
	Total	50.40	16.47	24
Interpretation	complex	34.52	30.12	12
	simple	12.50	16.08	12
	Total	23.51	26.16	24
Conceptual	complex	49.40	23.87	12
	simple	25.92	19.72	12
	Total	37.66	24.54	24

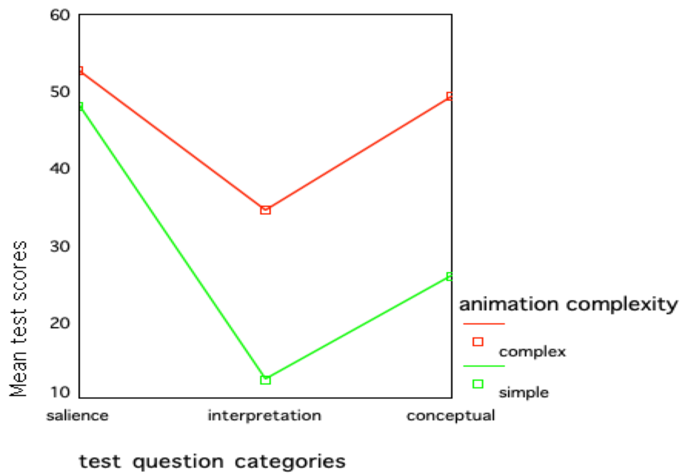
The MANOVA showed differences approaching significance according to complexity of animation ($p=0.07$). The between subject effects show no significant differences in the salience category, but significant differences in the interpretation ($p=0.03$) and conceptual ($p=0.01$) categories according to complexity of animation. However, Levene's test of homogeneity of variance was significant for the interpretation question category, therefore caution should be taken in interpreting results for this category.

Figure 7.3. Graph to show the effect of intermediate animation exposure on processing of different types of information



From the means those using the complex animation scored significantly higher than those using the simple (respiration) animation in those two question categories. The MANOVA also showed significant differences in performance according to question category (p=0.00). Repeated contrasts from a mixed ANOVA showed significant differences in performance between salience and interpretation (p=0.00) and between interpretation and conceptual categories (p=0.01). From the means and the graph it is evident that pupils scored higher overall on the salience and conceptual categories than interpretation (see fig. 7.3.).

Figure 7.4. Graph showing the effect of complexity on performance after intermediate exposure to animation.



(iii) Maximum exposure

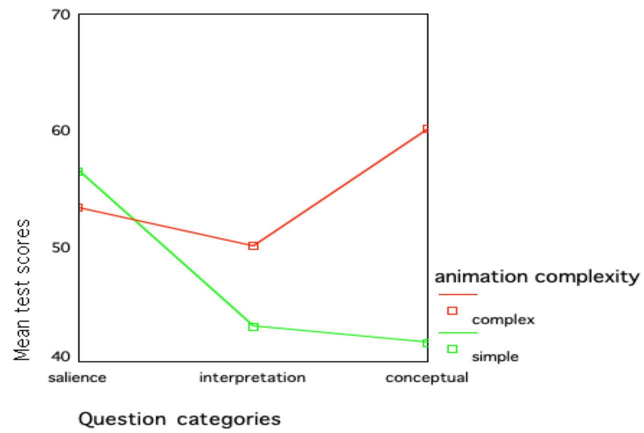
A MANOVA was again performed to compare the independent variable (complexity of animation) and the dependent measures variables (salience, interpretation and conceptual question categories) and look for any interactions (see table 7.3. for mean scores).

Table. 7.3. **Mean scores for complexity and question category in the maximum exposure condition**

	Complexity	Mean	Std. Deviation	N
Salience	complex	53.33	14.20	12
	simple	56.48	22.45	12
	Total	54.90	18.44	24
Interpretation	complex	50.00	37.30	12
	simple	43.05	32.14	12
	Total	46.52	34.23	24
Conceptual	complex	60.11	19.61	12
	simple	41.66	22.28	12
	Total	50.89	22.58	24

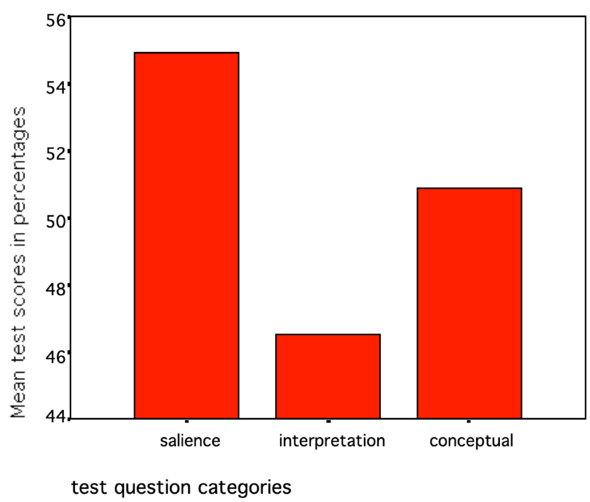
The MANOVA showed no significant differences according to complexity of animation overall. However, the univariate tests suggest that there is a significant difference in performance in the conceptual category according to complexity of animation. Those using the complex (heart) animation performed significantly better than those using the simple (respiration) animation on conceptual questions.

Figure 7.5. Graph showing the effect of complexity on performance after maximum exposure to animation.



A mixed ANOVA showed no significant differences between question category for the maximum exposure animation.

Figure 7.6. Graph to show the effect of maximum animation exposure on processing of different types of information



Summary

The complexity of the animations significantly affected performance in all exposure conditions, but in different ways in each exposure condition. In the minimum condition those using the complex animation performed better on salience and conceptual questions, in the intermediate condition those using the complex animation performed better on interpretation and conceptual questions, and in the maximum exposure condition those using the complex animation scored higher on conceptual questions. Not accounting for animation complexity, the interpretation category received the lower scoring in all exposure conditions.

7.4.2. Results of comparisons across all exposure conditions

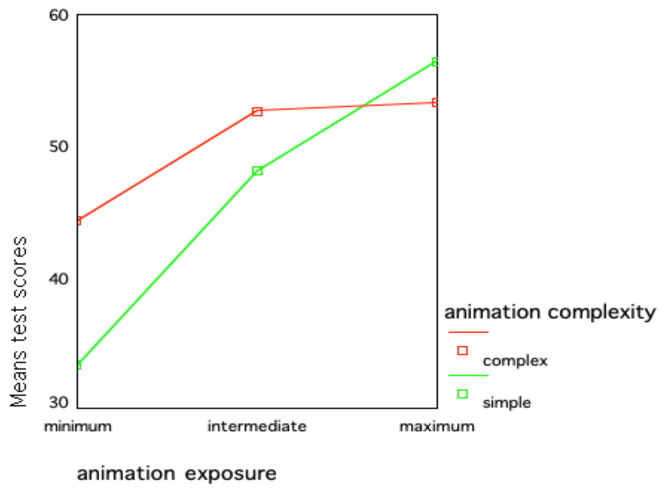
For these analyses all data were combined to enable comparisons of performance across all exposure conditions. A MANOVA was performed with animation complexity (complex and simple) and exposure (minimum, intermediate, and maximum) as independent variables, and test question category scores (salience, interpretation and conceptual) as dependent variables.

The analysis showed significant differences according to exposure ($p=0.00$) and according to complexity ($p=0.00$). Performance on the test questions was significantly affected by the exposure to the animation and by the complexity of the animation. The univariate analysis showed significant differences in all question categories according to exposure ($p=0.00$ for salience and interpretation, $p=0.02$ for conceptual). The means show that for all question categories scores increased with an increase in exposure to the animations. However, caution must be taken in interpreting results from the interpretation question category, as Levene's test of homogeneity of variance was significant for this category which reduces the reliability of the univariate analysis. The analysis also showed significant differences in performance on the conceptual question category according to complexity of the animation ($p=0.00$). The means show that those using the complex animation scored significantly better than those using the simple animation on conceptual questions.

Table 7.4. Showing mean scores for each question category according to complexity and exposure to animation.

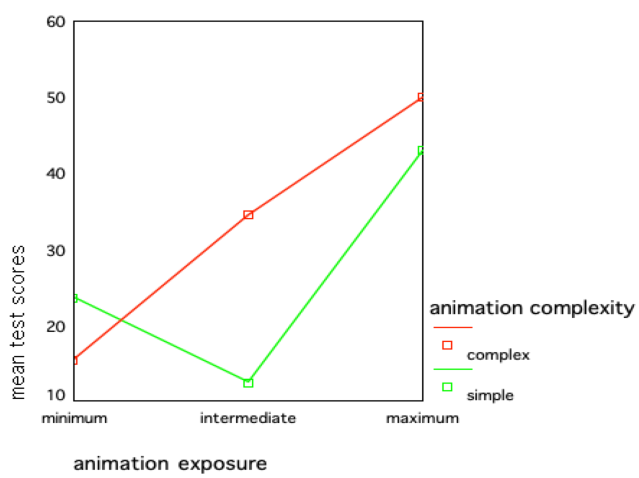
	Animation exposure	Complexity	Mean	Std. Deviation	N
Salience	minimum	complex	44.33	11.37	12
		simple	33.33	15.71	12
		Total	38.83	14.54	24
	intermediate	complex	52.66	17.37	12
		simple	48.14	15.94	12
		Total	50.40	16.47	24
	maximum	complex	53.33	14.20	12
		simple	56.48	22.45	12
		Total	54.90	18.44	24
	total	complex	50.11	14.70	36
		simple	45.98	20.25	36
		Total	48.04	17.69	72
Interpretation	minimum	complex	15.47	23.94	12
		simple	23.61	29.69	12
		Total	19.54	26.70	24
	intermediate	complex	34.52	30.12	12
		simple	12.50	16.08	12
		Total	23.51	26.16	24
	maximum	complex	50.00	37.30	12
		simple	43.05	32.14	12
		Total	46.52	34.23	24
	total	complex	33.33	33.28	36
		simple	26.38	29.10	36
		Total	29.86	31.24	72
Conceptual	minimum	complex	48.21	19.53	12
		simple	23.14	16.03	12
		Total	35.68	21.66	24
	intermediate	complex	49.40	23.87	12
		simple	25.92	19.72	12
		Total	37.66	24.54	24
	maximum	complex	60.11	19.61	12
		simple	41.66	22.28	12
		Total	50.89	22.58	24
	total	complex	52.57	21.19	36
		simple	30.24	20.67	36
		Total	41.41	23.63	72

Figure 7.7. Showing scores for salience according to complexity and exposure to animation



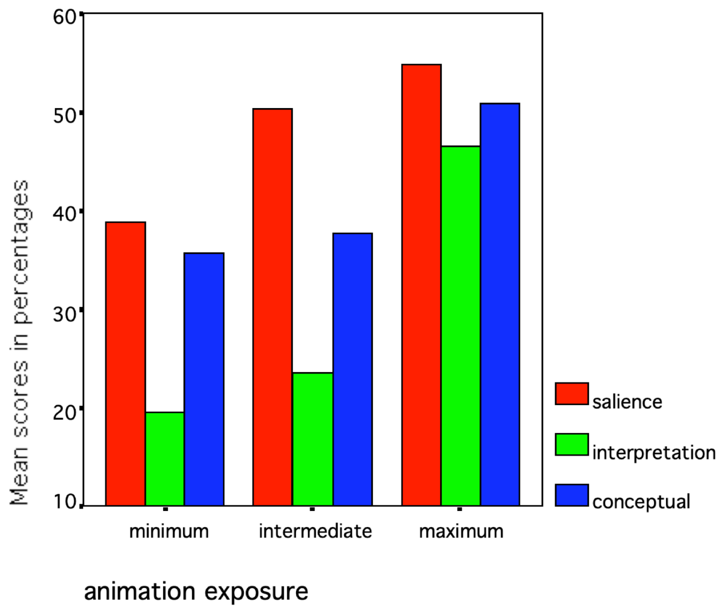
A repeated contrast showed a significant difference in performance for the salience category from minimum to intermediate exposure (p=0.01) and a significant difference in performance for interpretation and conceptual categories from intermediate to maximum exposure (p=0.00 and p=0.02 respectively).

Figure 7.8. Showing scores for interpretation according to complexity and exposure to animation.



Performance on salience question significantly improved from minimum to intermediate exposure (see graph 7.7), and performance on interpretation (see graph 7.8.) and conceptual questions significantly improved from intermediate to maximum exposure to animation.

Figure 7.9. Graph showing overall test scores according to question category and exposure to animation.



7.4.3. Errors analysis on individual question analysis

Detailed examination of individual questions from the test questionnaire was undertaken to establish whether any particular patterns of responses emerged that would inform us about the kind of processing taking place. Each category of questions was examined for evidence of patterns in performance level on each individual question, and any evidence of improved performance with increased exposure to the animation.

In the salience category both translation and transformation change were identified initially, but with increased exposure transformation was more accurately identified than translation change. For example, there was a substantial improvement with increased exposure to the respiration animation in identifying that the 'grey circle loses a blue circle and gains a red circle' (this is showing carbon dioxide leaving the cells and oxygen entering the cells in the capillary). This question was answered correctly by four out of twelve pupils in the minimum exposure, five out of twelve pupils in the intermediate exposure and eleven out of twelve pupils in the maximum exposure condition. There was no evidence of improved performance on accurately identifying translation change (primarily blood flow pathways) on the heart animation. After minimum exposure no pupils were able to give comprehensively accurate answers blood flow pathways, after intermediate exposure ten out of twelve were unable to give comprehensively accurate answers and after maximum exposure to the animation eight out of twelve were unable to give comprehensively accurate answers. Performance was consistently poor for feature presence change, for example there was no evidence of improved performance with increased exposure for identifying that the blue circle disappeared in the alveolar sac. This question was answered correctly by one pupil in the minimum exposure and two pupils in the intermediate and maximum conditions.

In the interpretation category performance was generally lower than for other question categories, although showed a larger improvement in performance after maximum exposure to the animations. In the heart animation the biggest score increases across exposure were for transformational interpretation. Scores on interpretation of translation change indicated no coherent pattern of understanding of blood flow pathways. In the respiration animation scores for translation interpretation were poor overall, and although some increases in interpretation performance were evident these were minimal, such that a maximum of five out of twelve pupils gave accurate responses to four of the six interpretations in the maximum exposure condition. In the conceptual category performance again was generally stable across all conditions, but this category in this study facilitated minimal elicitation of conceptual understanding.

7.5. Discussion

This section uses data from the above experiment investigating processing of dynamic information at the three different stages of learning.

7.5.1. Minimum exposure

- Complexity of animation

The results show that complexity (as defined in this thesis) significantly affected performance. After one run of the animation those using the heart (complex) animation scored significantly better than those using the respiration (simple) animation on conceptual questions and approaching significance on the salience questions. These results conflict with the concept that a more complex animation (in terms of levels of dimensionality and transience) will increase cognitive processing and effort, in which case one would expect scores of salience and interpretation to be higher for the simple than for the complex animation. However, during the period of data collection it transpired that pupils were being taught in class about the heart, but had received, (and were receiving) no teaching about the lungs or respiration. Thus, the level of prior knowledge between the two domains differed. Level of prior knowledge has been noted to influence learning with external representations (Brna et. al. 1997) and may have influenced performance with the animations for several reasons; (i) current knowledge might facilitate identification of relevant information, such as components, graphical change, which graphical changes mapped onto what they already knew, thus increasing their ability to notice and identify graphical change; (ii) not only was the level of prior knowledge different, but the instruction given was recent, making this domain (the heart) particularly relevant for pupils at that time, possibly influencing their ability to answer the kind of conceptual questions addressed in this study; (iii) the difference between these groups was apparent on a visuo-spatial level (the salience of the graphical change). Lowe (1994) suggested that low domain knowledge users used visuo-spatial aspects of the diagram to drive their processing, and although those using the heart animation were unlikely to be 'experts', they may have had more internal cognitive tools with which to 'drive' or direct their processing, facilitating their visuo-spatial processing of graphical change. Therefore, the most likely explanation for the results obtained here is the effect of the level of prior knowledge on ability to read certain aspects of the animation. Two issues emerge from this proposed finding:

(i) Possible contribution to a cognitive processing model

If we look at performance on reading graphical change, we can begin to see where prior knowledge may influence processing. The analysis showed that those using the heart animation performed better on salience of graphical change than those using the respiration animation, but not on interpretation questions. This may suggest that higher prior domain knowledge facilitates perception and identification of graphical change, and serves to appropriately guide and focus learner attention. This may suggest that focusing attention on appropriate dynamic aspects is an important part of noticing and identifying graphical change. However, despite higher prior knowledge pupils performed poorly on the interpretation of graphical change questions. This may be a more complex aspect of processing at this stage of viewing the animation.

(ii) The issue of defining complexity.

The events here suggest that complexity as defined prior to this experiment are not the only dimensions of complexity to be taken into account when processing animated diagrams or indeed any diagram. Complexity may also be defined in terms of the level or even type (general or domain specific) of 'internal' cognitive resources available to pupils when interacting with the external representation. The knowledge or perception already present cognitively influences the way the external representation is perceived and interpreted. De Groot (1965) showed that expert chess players used information from a chess display significantly differently from novice chess players. Experts not only recognised more meaningful chess configurations, but organised the information into chunks that related to specific functions or strategies. Chunking meaningful information also facilitated their memory of what they saw. Similar results have been found in mathematics (Hinsley et. al 1977), electronics (Egan and Schwartz 1979), computer programming (Ehrlich and Soloway 1984). This factor deserves further research which would provide another dimension to the cognitive model of animation being developed here. Investigation targeting interactions specific to previous knowledge and post animation understanding would be beneficial (see chapter 9 for more detail). These results may also suggest that the effects of transience and multidimensionality of the representation are counterbalanced by some level of prior domain knowledge. It is possible to imagine that the interaction of prior domain knowledge and transience or multidimensionality of the representation significantly affect the effectiveness of the representation and are, therefore, important design considerations.

- Graphical change

In terms of graphical change, overall the results showed that salience and conceptual questions were answered significantly better than interpretation. This suggests that after one run of the animation, regardless of complexity of animation or prior knowledge, graphical change is accurately noticed and identified more than it is being interpreted. At this stage pupils focus more on the salient attributes of the graphical change than the interpretation.

7.5.2. Intermediate exposure

The results of intermediate exposure to animation suggests that processing of graphical change is potentially affected by level of prior knowledge, and that progressive stages in processing are taking place.

- Complexity of animation (or level of prior knowledge)

Those using the heart animation performed significantly better than those using the respiration animation on interpretation and conceptual questions. Thus, after more exposure to the animation those with the higher prior domain knowledge continued to perform better on particular aspects of processing graphical change than those with lower prior domain knowledge. Although those using the heart animation did significantly better than the respiration animation in interpretation of graphical change, there was no significant difference between animations in the salience category. This may suggest that increased viewing brings lower prior knowledge pupils in line with higher prior knowledge pupils in the context of noticing and identifying graphical change, thus showing no significant difference in salience between the two animations. Thus, when there is low prior domain knowledge salience of graphical change is no more difficult to assimilate than with high prior domain knowledge after an intermediate number of runs of the animation, but interpretation of that graphical change is still significantly different, interpretation of the heart continuing to be potentially facilitated by increased prior knowledge (although it must be remembered that homogeneity of variance was not found for this dependent variable in the MANOVA). This suggests that a progression in processing may occur from noticing and identifying to interpreting the changes taking place on the diagram.

- Graphical change

The analysis showed significant differences in performance according to the question category, specifically between salience and interpretation, and interpretation and conceptual. Regardless of complexity pupils scored higher on salience than on interpretation questions. This suggests that after an intermediate number of runs pupils were still focusing primarily on noticing and identifying graphical change, but not yet accurately interpreting those changes in relation to the diagram. This suggests that processing of salience of graphical change occurs prior to interpretation of the change or that interpretation of change is facilitated by the level of internal domain knowledge. The graphs show that performance dramatically decreased from salience to interpretation, but then improved for conceptual questions (see graph 7.3.). This might suggest that overall conceptual understanding may not necessarily be dependent upon appropriate interpretation of graphical change. However, it is more likely that general prior knowledge of the domain was sufficient to answer the minimal number of conceptual questions in this particular test without relying on the interpretation of graphical change in the animation.

7.5.3. Maximum exposure

The results of the maximum exposure to animation showed two relevant aspects for informing about processing of graphical change.

- Complexity of animation (or level of prior knowledge)

Overall no significant differences in performance according to complexity of the animation were evident. This suggests that, after the maximum number of animation runs, the ability of lower prior domain knowledge pupils to process graphical change was by this stage similar to those with higher prior domain knowledge. This suggests that improvement on salience and interpretation of graphical change had (as a minimum) taken place for those with lower prior domain knowledge. However, there was some evidence that conceptual questions were better answered by those using the heart animation. Reasons for this are again likely to be due to potential effects of prior knowledge, combined with the particular questions used in this study.

- Results in relation to graphical change

The analysis showed no significant differences in overall performance between question categories, the pattern remaining the same as for other exposure conditions. Thus, pupil performance deteriorated from salience to interpretation but improved again for the conceptual questions regardless of complexity or domain knowledge. However, it can be seen from Fig. 7.3. that the pattern of knowledge for the heart animation differs from that of the respiration animation. In the heart animation scores for salience and interpretation were similar, whereas in the respiration animation scores deteriorated from salience to interpretation to conceptual questions. Those using the heart animation performed significantly better on salience questions after one exposure to animation, thus, processing progression patterns may be different with increased exposure to animation. By this stage similar scores fro salience and interpretation suggests that with increased exposure interpretation is placed on identified graphical changes. However, scores overall are not high for any category, suggesting that noticing and identifying and interpreting is an iterative process. This will be discussed in more detail in section 7.4.4. where data across all conditions will be addressed.

7.5.4. Minimum, intermediate and maximum exposure

- Animation exposure

The results showed that exposure to animation significantly affected scores in each question category. From the means it is evident that in all question categories scores increased with an increase in exposure to animation (see table 7.3. and fig.7.6.). This is not a surprising result, as one would expect increased viewing to improve recall of the salience and interpretation of graphical change. This confirms that understanding graphical change is a gradual process of increasing the number of graphical changes identified at the same time as increasing the number of changes interpreted.

- Complexity of animation (or level of prior knowledge)

The results showed that those using the complex animation performed significantly better on conceptual questions than those using the respiration animation. This is probably a product of the particular questions used and more detailed intensive elicitation of conceptual aspects would be beneficial in clarifying the effect of animation on higher conceptual understanding. However, the results show no significant differences

- Graphical change

The results show that there is a significant difference in salience scores between minimum and intermediate exposure, thus increased exposure to the animation at this level resulted in an increase in the amount and type of graphical change noticed and identified. Processing at this stage appears to focus primarily on noticing and identifying changes, more than interpreting those changes. Reading diagrams in static format requires learners to identify features and relationships between features, read any text etc.. in order to understand the diagram. Therefore, reading an animation also requires the learner initially to see 'what's going on'. With this kind of external representation this means identifying features that are moving. The fact that pupils noticed and identified dynamic features initially and increasingly across exposures may be due to at least two factors; *(i)* that the movement on the animation attracts attention; *(ii)* that identifying features of a diagram is a task that is familiar in that it is similar to the requirements of reading a static diagram.

However, an animation, because of the dynamic change (be it transformation or translation) requires a reader to also interpret not only the meaning of the graphical object itself, but also the meaning of the graphical changes occurring. Accuracy of interpretation of graphical change only improved significantly after maximum exposure to animation, which may suggest the following; *(i)* that interpretation is processed after identification. Once a certain amount of graphical changes have been identified processing of interpretation of these changes begins to take place. Furthermore, the amount of changes noticed and identified after increased exposure levels out at the time that an increase in interpretation is occurring (see fig. 7.7. and fig. 7.8.). The salience scores show that there are still a substantial amount of graphical changes to be noticed and identified even after the maximum exposure to the animations, which suggests that an iterative process of noticing, identifying, and interpreting is taking place. User activity has been described as being cyclical or iterative in nature (Green 1989). This conception can also be applied to diagrams such that information is being returned to at some time during the integration process. In this way the use of the diagram is iterative in the sense that it is being re-used, most likely in a slightly different or modified way than before; *(ii)* That interpretation is more cognitively demanding than noticing and identifying. It may be the case that interpretation of graphical change is more cognitively demanding than interpretation of graphical objects from, for example, a static diagram. Reading graphical change requires understanding the current representation (e.g. red dot representing oxygenated blood), identifying the change (change in colour from red to blue), and understanding the new representation of the feature identified (blue dot representing deoxygenated blood). This is arguably more cognitively demanding than having to 'read' features that do not undergo this explicit change. In addition, expertise in reading animation/dynamics may be limited. Interpretation may be hampered by inexperience with working with animated diagrams, and interpreting graphical change, resulting in less cognitive attention and effort applied to this task.

From the graph (fig 7.9.) it can be seen that scores in the conceptual category improved from the minimum to intermediate condition, and from intermediate to maximum exposure. This may suggest that more identification of graphical change enables integration of the identified aspects with a more general conceptual understanding, but little conclusion should be drawn regarding conceptual understanding as this was a side issue in this study with minimal focus in assessment measures.

7.5.5. Analysis of individual questions

These results will be discussed under each question category heading.

Salience. Patterns of answers in the salience category suggest no definitive pattern of processing transformational or translation change. However, in the initial exposure to animation identification was primarily transformational, for example on the heart animation, noting that the blue dots changed to red and vice versa, and with increased exposure on the respiration animation noting that the grey cell loses a blue circle and gains a red circle. Although some translation change was distinguished transformational change appears to be more readily identified. It may be that transformational change, on the animations in these studies exclusively takes place in one location, whereas translation change requires tracking movement across differing locations and over a longer period of time. This requires an intention to follow movement, and that attention be maintained on one graphical object for a longer period of time than for transformational change, and therefore runs the risk of attention being interrupted by other movement before processing of the full 'tracking' has taken place. If this is the case then translation change may be more cognitively demanding to identify accurately. It might be that the same effect would occur with transformational change that occurred over a longer period of time. In the animations used in this thesis transformational change is generally rapid, but other animations may show slow transformations. If cognition was affected in these circumstances, then the speed of graphical change may be instrumental to cognitive processing. The results also suggested that graphical change, such as feature presence is not readily identified. This kind of change in the display is perhaps not so explicit or apparent as translation and transformation. However, scores noting that the red circle appeared (respiration animation) increased with exposure, whereas the disappearance of the blue circle (respiration animation) did not. This may suggest that appearance of a new feature is more readily identified than the disappearance of current feature.

Interpretation. Analysis of questions relating to interpretation shows that correct interpretation of transformational change increased with an increase in exposure to animation. For example, interpretation of change of dots from blue to red and red to blue was more accurate with more exposure to animation. If pupils notice this event then this may demonstrate a cognitive progression, from identification to interpretation. The number of subjects seeing or noticing that dots change from red to blue and blue to red is the same after minimum exposure as after intermediate exposure. This suggests then, that the salience of the event is processed early on, but that more exposure to the animation facilitates accurate interpretation of this event. Accurate interpretation of translation change was generally poor. This is most likely related to the degree to which each translation movement has been identified. It would be reasonable to assume that difficulty in accurate full identification of the movement would result in problems with accurate interpretation. It was clear from detailed examination of the answers on blood flow that there was no evidence of a coherent pattern of understanding the blood flow pathways. Overall the answers given suggest that pupils were confused about where the blood flowed to and from, as both oxygenated and deoxygenated blood were perceived as flowing into the heart both from the lungs and the body. The distribution of these answers was not notably different.

7.5.6. Summary discussion

From the above results it can be seen that the level of prior domain knowledge affects the level of processing of graphical change at different stages of exposure to animation. Those with higher prior domain knowledge were able to both perceive (notice and identify) graphical change better after minimum exposure to animation, than those with lower prior domain knowledge. However, after intermediate exposure no difference was apparent in the salience category between the two groups, but a difference was evident in the interpretation category. This suggests that increased exposure to animation facilitated increased accurate perception of graphical change in the respiration animation (lower prior knowledge), but was not yet sufficient to bring about improved interpretation of graphical change, whereas increased exposure in the heart animation (higher prior knowledge) facilitated interpretation of graphical change. After a further increase in exposure to animation a difference in interpreting graphical change was no longer evident. However, neither group scored particularly highly on any question category. This might suggest that further exposure to animation (or even other factors, such as learner guidance) may be necessary for improving understanding of graphical change and integrating that information in order to make inferences required for higher level conceptual understanding. The conceptual questions in the test, however, were not sufficient to comprehensively assess conceptual understanding. Further specific research on inferences from graphical change would be fruitful.

Overall there is evidence to suggest that some prior knowledge facilitates focus of attention and identification and interpretation of graphical change, but may not necessarily facilitate increased conceptual understanding. There is also evidence from learners that salient aspects of the dynamics are processed prior to interpretation of the dynamics, and that both of these aspects improve with increased exposure to animation. As there is no evidence of an increase in conceptual understanding, the amount of exposure to the animation may not have been sufficient for this kind of integration of information.

Detailed examination of pupil answers suggest that translation and transformation change may be processed differently, and that this may be affected by, for example, speed of change (in terms of number of frames as well as speed of frames), or dimensionality of the representation. Additional research may serve to clarify these issues further.

7.5.7. Limitations of conclusions drawn

(i) From the results it is apparent that generally learners were unable to identify and interpret all of the graphical changes that took place on the animations within the number of loops used in these studies. To establish further information it may be necessary for learner to view the animations for longer at each run, or encounter more exposures. It may be that a limited threshold for processing graphical change exists, thus that no more changes are identified or interpreted.

(ii) Conclusions about processing of salience and interpretation of graphical change is based on the animations used in these experiments. This meant that not all possible variables in terms of the kinds of graphics used were incorporated into the design. It might be, therefore, that perception, identification and interpretation of graphical change are also affected by the relative grossness of the change, the relative brightness of the colour, the relative size of the object changing or the particular location on the diagram.

7.6. Limitations of experimental design

During data collection and analysis several limitations of the experimental design and alternative ways of examining proposed issues within this study became apparent.

7.6.1. Complexity investigation

Using two different topics in this particular instance resulted in confounding variables, as due to the teaching program within the school, pupils using one animation were being taught the related topic while those using the other animation had had no teaching about the related topic. This meant that pupil expertise in the domain differed, which no doubt had an effect on the results and the conclusions that could be drawn in terms of comparisons in cognition according to complexity of the representation as defined in this research. An alternative way of investigating this would be to use a simplified version and a more complex version of one topic, rather than two different topics for investigating complexity.

7.6.2. Animation design

A number of design aspects of the representation resulted in some ambiguity of information. For example, the respiration animation showed flow of 'air' in and out of alveolar sac using static arrows, which were frequently unnoticed. Several pupils suggested that this event or action would have been clearer if the red and blue dots (representing oxygen and carbon dioxide) had continued to flow in and out through the entrance to the alveolar sac. This would have resulted in a more consistent representation of those substances, and made the continuation of their movements more apparent through representational continuity. However, these particular design aspects were not considered to undermine the results of the study, although they do have implications for designing animations in terms of continuity of representation type and clarity.

7.6.3. Test design

Designing assessment tests is a complex process and during analysis of test questions it became apparent that some questions were redundant. These questions were isolated during analysis, but were not found to cause significant differences in results. Using two different animation domains demanded different sets of questions, therefore, potential inequality in terms of complexity or ease of questions was present. The conceptual category of questions comprised of a limited number of questions which may have been inefficient in generating comprehensive information about conceptual understanding.

7.6.4. Procedures

An alternative way to establishing steps in understanding the salience and interpretation of graphical change would be to have the same participants in the minimum, intermediate and maximum exposure conditions, answering questions between each condition, using split file technique. This would establish more clearly the kinds of links and cognitive progress made by individuals, and may show regular patterns of cognition, suggesting different strategies of learning. However, using this design would mean longer pupil participation time. Pupils participation time within the school was limited as pupils were taken out of class time to take part in the studies.

7.7. Conclusion

Chapters six and seven provide information about possible methodologies for evolving a cognitive model of processing animation, and show the importance of detailed analysis of pupil learning to inform about cognitive interaction with animation. This chapter has looked in more experimental detail at the effect of the salience or visibility of graphical change on cognition and has also discovered the importance of interpretability of the graphical change in understanding animation. The next chapter goes on to look at parsability of an animation, and the effectiveness of this on integrating information.

Chapter 8

Processing animation: How information is integrated from a dynamic representation.

8.1. Summary

This research has concentrated on looking at cognitive processing of animation by focusing on the properties specific to animation, and investigating learning in relation to these properties. Studies and experiments in the previous chapters have focused on the perceptual salience and the understanding of graphical change, (a dynamic property inherent to animation) within a proposed cognitive model of learning with dynamic representations. These studies suggested that some progression in understanding occurs from identifying graphical change to understanding the meaning of the graphical change, but also suggested that the type of graphical change itself may be instrumental in subsequent interpretation of the change and consequent clarity of conceptual understanding. In terms of cognitive dimensions of animated representations (visibility demands, akin to Green 1991 role-expressiveness) this suggests that not only is visibility of the representation a dimension to be considered, but also interpretability of the representation. As well as providing evidence for an additional dimension to role-expressiveness, the studies also demonstrated how learners extract and use information from animated diagrams, highlighting design issues for animation *(i)* in terms of its graphical change, such as, the explicitness of the type of graphical change, for example, whether the change is identified by the learner as transformation or translation will affect the interpretation and meaning derived from the dynamics, and *(ii)* in terms of the guidance that may be given to pupils, for example, guidance in focusing their attention to specifically relevant graphical changes, making them more salient.

However, whether relevant information is attended to and processed due to its perceptual salience or due to guiding attention, is only one factor towards fuller understanding. Green's (1991) definition of role-expressiveness entails the cognitive dimension of parsability of the representation as well as visibility. Thus, a model of learning from an animation not only includes visibility and interpretability of graphical change, but also consists of parsing the diagram into appropriate sections. In addition, the importance of coherently integrating relevant pieces of information has also been highlighted. “The ability to translate and integrate new and stored knowledge is critical to understanding and being able to reason about a domain” (Rogers 1999, p.8). In terms of animation this means integrating information derived from both graphical change, other diagrammatic components, and domain relevant events. The studies in this chapter investigate ways in which integration of information from the animation may take place, based on concepts raised regarding domain parsing in chapter three (3.3.1.ii).

8.2. Introduction

Complexity of animated information in terms of an increase in perceptually available information, potentially resulting in high dynamic information load and in memory overload, could point to the importance of learners being able to break down the information into smaller components, in order that adequate comprehension or relevant reading of dynamic representations can take place. Kaiser et al. (1992) found that where only one dimension of the dynamic information was present then animation facilitated accurate observation. This suggests that the number of simultaneous dynamic events is cognitively influential and that 'parsing' of dynamic events may be important in facilitating correct dynamical judgment. If learners were able to isolate the different dynamic events, then this may suggest that parsing the dynamics into single dimensional units is feasible and it may also facilitate understanding. Studies one, two and three provided evidence that learners, to some degree, spontaneously parsed information in particular ways, and appeared to take in small amounts of information at one time, gradually combining their knowledge with previously acquired pieces of information.

However, although the previous experiment focused on salience and interpretation of graphical change, pupil performance in these studies also suggested that integration of those features was lacking in building a coherent picture of the dynamic system being displayed. Successful integration of information may be affected by several factors. On a general level such aspects as, previous knowledge, learner task or even cognitive style may affect a learner’s ability to integrate information. In terms of diagrams, integration may be affected by aspects such as the frame of reference, identifying relational components, or successfully ordering pieces of information (e.g. Witrock’s (1989), Narayanan and Hegarty 2000).

Research into understanding any representation, be it text, speech, graphics has cited the importance of 'parsing' the information into smaller understandable components (e.g. Rieber 1990, Green 1991).

Although, these are critical to successful comprehension, on a more specific level integrating information from an animated diagram may be problematic for reasons relating to the fundamental properties of animation. The basic form of animation immediately renders the information into a series of multiple representations. This means that understanding an animated diagram requires the integration of information across multiple changing representations. The learner is, therefore, required to remember previous transitory information (e.g. object location, relational components) to order and integrate. Decomposition into smaller components prior to reintegration is more complex with animation requiring the learner to identify and segregate not only domain relevant sub sets, but also graphical change mechanisms, and integrate information across these two aspects. One important facet of integration is to make coherent and relevant links between all these various types of information accumulated from the representation. Thus, relevant properties of animation in relation to integration of information relate primarily to cognitive overload in terms of: *(i)* the transient nature of the representation precluding learner control in reaccess to information (Stenning 1998), which may be important in integrating information coherently, and *(ii)* the large (even unmanageable) amount of salient perceptual information being displayed (Kaiser et al 1992), impeding focus of attention.

The proposed learning model (chapter three) suggests that to understand from an animated diagram a learner must first notice and identify graphical change (which may be in the form of translation, transformation or feature presence). This graphical change must in turn be interpreted in terms of its representational meaning, and these meanings or interpretations be linked together to produce a coherent understanding or model of the dynamics of the system. For an animation this involves understanding that a movement of an object from one place to another must be understood in terms of what it is representing, and how this relates to another object moving from one place to another, or to the same object making a further movement, and to the static components of the diagram. It also entails understanding the relationship between a transformational change and a translation change. For example, in the heart animation this would mean understanding that the movement of deoxygenated blood from the heart to the lungs is related to the transformational change from blue (deoxygenated) to red (oxygenated) in the lungs, which is also related to the translation change of oxygenated blood from the lungs back to the heart, in terms of the functionality within the cardiac system. Noticing, identifying and translating a graphical change alone is not sufficient for full understanding of a system, understanding the relationship between one graphical change and another is important in determining comprehensive meaning about the dynamics of the domain. It seems to reasonable to assume, therefore, that there are four broad steps to this learning process; *(i)* identifying separate pieces of the dynamic information, *(ii)* interpreting this graphical change *(iii)* identifying separate components or subsections of the diagram and *(iv)* integrating all of these pieces of information to make a coherent whole. The latter two of these is the focus of this chapter.

Studies one and two (comparison of animated and static representations) and study 3 (perceiving and understanding graphical change) both provided information which is pertinent to issues relating to integration of information from animated diagrams. In study 1 the manner of structuring information (through task) was found to be predictive of performance whether using an animated or static diagram. The results from this study relating to differences in task type, primarily suggested the importance of organising information for learning, not only in terms of guiding learners towards specific pieces of information, but also in terms of ordering the aspects they attend to, in such a way that it enhances integration of information. Studies one, two and three all generated evidence of patterns of attention focus suggesting ways in which pupils ‘parsed’ the diagram and structured the information they were studying. Focusing attention and sequencing information relieves learners from deciding which aspects are important and in which order to 'read' information. This may reduce confusion, enhance focus of attention on relevant aspects, and facilitate integration of information. Study 3 also suggested that with animated diagrams learners are required to integrate dynamic features with static features of the representation, and although this characteristic may sometimes arise due to design features (e.g. the respiration animation in this thesis showed flow using static arrows combined with explicit dynamics), the necessity to integrate static with animated features remains.

Studies one and two showed errors in understanding that related to Green’s (1998) concept of hidden dependencies, and was identified in this current research as peripheral dependencies relevant to comprehensive understanding about a system (see 4.3.3.). This dimension refers to the provision within the representation to convey ‘peripheral’ processes that are integral to understanding the specific process depicted in the animation, for example, the process of gas exchange in the lungs and the body for understanding cardiac circulation. Evidence from previous studies in this thesis suggest that peripheral process information is not well integrated with information about the depicted system by learners. The studies on graphical change suggest that pupils identified the relevant transformational changes of the blood, but it was not clear whether this information was integrated into and related to cardiac circulation.

To investigate integration of information it is necessary to consider the kinds of links pupils make or do not make, and whether or not these links result in comprehensive understanding. This study examined these aspects by providing diagrams with smaller pieces of information from which links could be made and pupils were tested on whether or not these links were achieved and whether this contributed to their understanding. The animations were, therefore, ‘parsed’ and presented in identifiable domain specific (as oppose to graphical change specific) components (see chapter three). Thus the focus was to use different stand alone sections of information that could be combined, rather than individual dynamics, such as one transformation or translation event. The appropriate components were constructed in an order concurrent with previous research (study 1 and three) for the purpose of integration. However, when information is divided up, representations automatically become multiple, e.g. there may be six different diagrams showing smaller amounts of information instead of one. Research suggests that integrating information across representations can be problematic (Rogers and Scaife 1997, Hoogeveen 1997, Kim and Hahn 1997). There may be several reasons for this; the amount of visual search required to find related information from different representations (Kim and Hahn 1997); information not being simultaneously available on the screen, causing the learner to have to remember information from one ‘screen’ to another and make links without the previous information being present (Rogers and Scaife 1997). The concept of dynalinking, (where different representations are simultaneously presented together with explicit links between representations) has been shown to facilitate integration of information due to the proximity of the representations and the explicit demonstration of relational elements, and cause and effect (Rogers and Scaife 1997). Although dynalinking also used different kinds of external representations across which to share information, nevertheless the need to integrate information from one screen to another was removed. To encompass this finding, animations can be designed in such a way that the whole animation continues to run on the screen, while a particular section of the diagram is simultaneously visibly more explicit. This also enables parsing of the animation, which inherently guides attention focus, at the same time as maintaining links between the more visibly explicit information and the rest of the animation. Structuring the animation in this way enables the investigation to focus on whether or not pupils make relevant information links between one section and another.

During design of the parsed animation, two different ways of presenting the decomposed information emerged (either adding each new component to the current display or substituting one component for another). This also enabled investigation into the effectiveness or not of focusing learner attention to specific domain aspects, and ordering the information in a relevant fashion. Decomposing the animation for the learner removes one step of the cognitive load required to understand the animation. Therefore, not only can integration of information be identified, but also the benefits or disadvantages of 'parsing' the animation in terms of overall learning.

In studies four and five two animations were employed, the original rationale being an issue of complexity in terms of, for example, the quantity of dynamics, multidimensionality, to establish whether differences in processing existed between the two kinds of representations. However, in this study the ability to integrate information was established through animations where information was pre parsed, and although there may be differences in processing with dynamics of more or less complexity in terms of the number of sections to parse and integrate, the use of one animation was considered to be sufficient for investigating how information from an animated diagram may be integrated. The heart animation was selected for this purpose, as it provided more parsing facility and was more complex in terms of amount, and dimensionality of information.

Thus, using identified properties particular to animation as a basis for understanding cognitive processing specific to this kind of representation, the aim of this study is twofold: *(i)* to investigate the relational links that may or may not be being made, and *(ii)* to identify ways in which integration may be facilitated given the documented difficulties inherent in an animated representation and the preliminary findings in study 1. This study was, therefore, divided into two parts:

Study 5: description generation of cognitive processing when integrating information from an animation.
Study 6: experimental evidence of the effectiveness of different parsing manipulations on an animation.

8.3. Study 5

The aim of this study was to generate a description of the cognitive process of integration of information using an animation. Two different parsing manipulations were used on the heart animation. Data was obtained through verbal protocols from pupils between each addition of parsed sections of the animations, as well as a written post test.

8.3.1. Method

Participants

Participants were sixteen year 8 pupils from a Comprehensive School who were novel to this research. Ten were female (mean age = 13 years 3 months; 159 months, sd = 3.9 months)and six were male (mean age = 13 years 2 months; 158 months, sd = 2.5 months). Pupils were taken from mixed ability science classes, thus providing a distribution of ability across experimental conditions. Pupils worked in pairs as allocated by their teachers on the basis of working well together.

Materials

(i) The animations (see CD ROM provided)

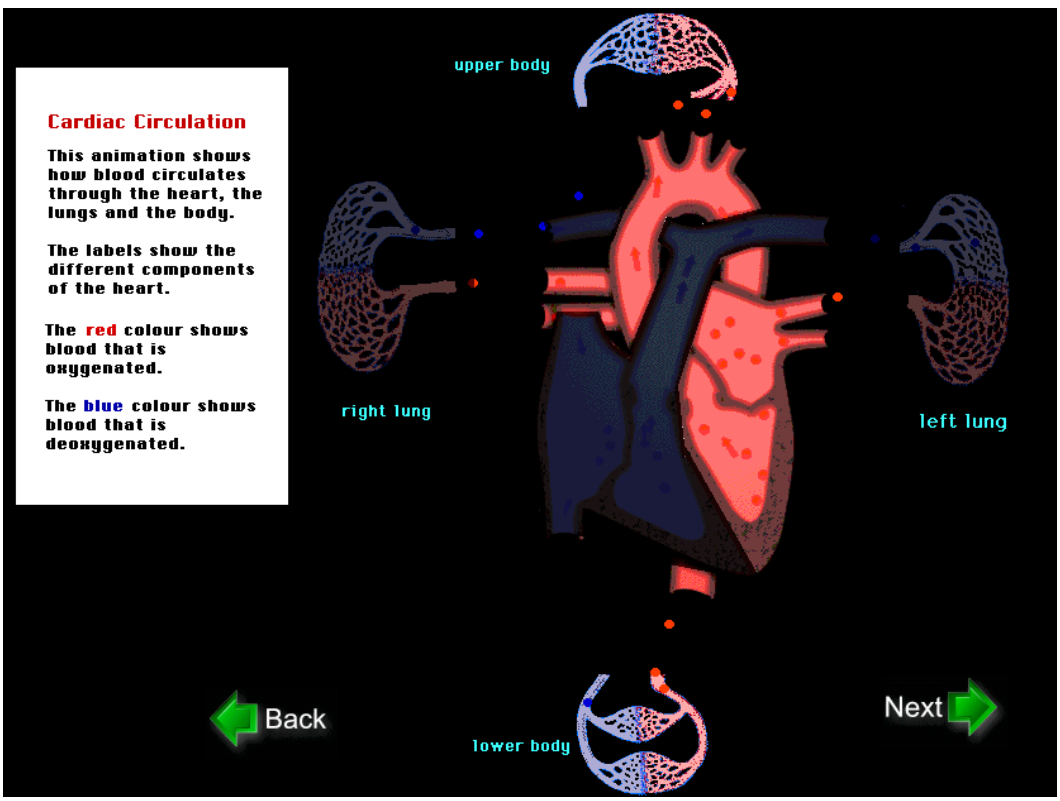
The heart animation from the immediately previous studies was used as a basis for this experiment, with particular modifications in relation to parsing. The modifications consisted of parsing the information into six smaller coherent sections. The basis for the manner in which the information was to be parsed was taken from previous experiments showing patterns of order of information attendance, and processing of graphical change in terms of its salience, with the focus being on learning blood flow through the heart and the circulatory system.

In this experiment parsing the animation was implemented in Multimedia Director through the use of masking. The selected subsections of the animation were made visually explicit, while the rest of the animation was still present but masked, such that it was dimmed, making it less likely to draw attention. The rationale for maintaining the animation in the background was to avoid placing the selected parsed section out of context of the rest of the animation, in accordance with conclusions from previous research (e.g. Scaife and Rogers 1997). A consequence of this was that in order for the masking to merge with the rest of the diagram the background of the animation had to be black as oppose to the white background used in the previous studies. The visually explicit subsection changed or increased (according to experimental condition) on a mouse click by the user. In order that pupils had a coherent frame of reference prior to viewing the parsed animation, the display initially consisted of the whole diagram in static format. A static diagram provides the context and frame of reference without exposing the dynamics of the animation. If pupils were exposed to animation prior to manipulation this could have some influence on their processing of the parsed animation. The final design of the mini program, therefore, shows an initial static representation of the heart together with some textual information explaining what the diagram was showing and explaining that blue represented deoxygenated blood and red represented oxygenated blood. A play button was provided for the learner to begin the animation when ready. The animation began with all areas masked, so that when the first masked area was uncovered, the content of the revealed information was clearly evident (see CD ROM).

- Additional parsed animation

The animation began with the heart diagram in static form. The learner was required to click a "PLAY" button to begin the movie. The movie then began with all parsed sections masked. A "NEXT" button enabled the learner to go to the first parsed section. Another click on the "NEXT" button took the learner to the second parsed section. This parsed section was displayed together with the previous one, while other parsed sections remain masked. This pattern continued until all parsed sections were simultaneously displayed. In this manipulation each parsed section displayed was *additional* to the previous parsed section(s). During the animation the learner always had the facility to go to the previous parsed section by clicking on a button labelled "BACK".

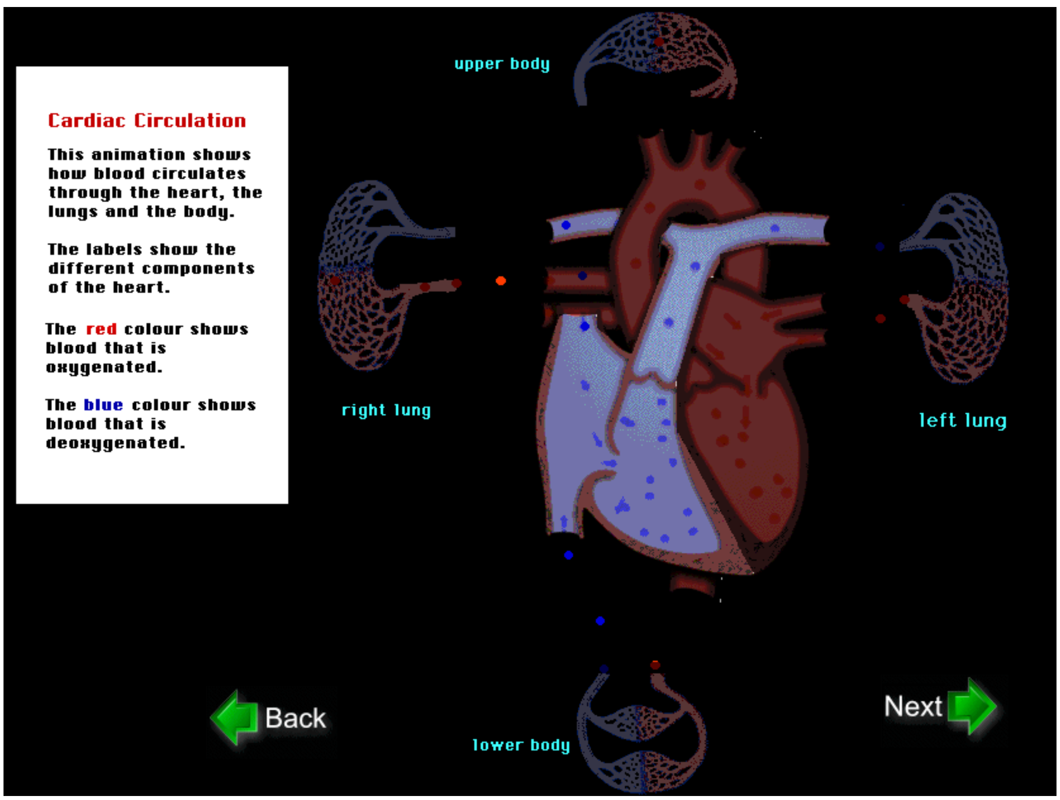
Figure 8.1. Example frame from additive parsed animation, showing three revealed sections of the parsed animation.



- Substitute parsed animation

The animation started with the diagram in static form. The learner was required to click a “PLAY” button to start the movie. The movie then began with all parsed sections masked. A “NEXT” button enabled the learner to go to the first parsed section. Another click on the “NEXT” button took the learner to the second parsed section, but unlike the additive parsed animation, as this parsed section was displayed the previous one became masked again. This pattern continued until all parsed sections had been displayed. At this point the learner could view the full animation. During the animation there was always the facility for the learner to go to the previous parsed section by clicking on a button labelled “BACK”.

Figure 8.2. Example frame from substitute parsed animation



The animations were run on Macintosh PowerBooks in a laboratory in the school. The lighting conditions were such that masking was set at 90% transparency, in order that the masked parts remained visible, but distinctively different in visual explicitness that the non-masked sections. As the angle of the screen significantly affected the visibility of the masked sections, each time the screen was checked for optimum positioning. The animations consisted of 90 frames, and were played at 25 frames per second.

(ii) Task

A fairly general task was chosen so that pupils attention was not too specifically directed, enabling more explorative kind of research. Pupils were informed that their task was to find out as much as they could about how and where the blood flowed through the heart and the circulatory system.

(iii) Testing and analysis

Verbal protocols were recorded from participants between each addition or change of the parsed subsections of the animation. This produced information for generating a description of the cognitive process of integrating information, providing both correct interpretations and errors in understanding, and establishing when, if or why errors were corrected.

(iv) Assessing learning outcomes

Learning was assessed using a written test and a computer presented diagram test (see appendix 12a for pre tests, 12b for post tests). Using two different representational formats for testing may provide more comprehensive information about knowledge representation, and integration of information by using cross representational formats (Mintzes et al. 1999). The written test was designed to focus on links between pieces of information, and assess understanding of higher level conceptual issues, such as, the links between the heart and the processes within the lungs and the heart and the processes within the body. The optimum way of designing pre and post tests in this experimental environment was considered to be to use a split half technique giving half of the subjects test A as a pre-test and test B as a post test, and the other half of the participants test B as a pre-test and test A as a post test. This served two functions: firstly, it enabled analysis of levels of prior knowledge to establish any differences that may have existed between experimental groups, thus confirming uniformity of knowledge across experimental conditions. If uniformity of prior knowledge exists, then any differences in learning between experimental groups cannot be attributed to differences in prior knowledge: and secondly, it enabled comparison of performance between pre experiment and post experimental effects, by using the same test in a split half technique. This means that any differences in learning can be attributed to the experimental effect. For the diagram test (see appendix 13) pupils were required to note the numbers displayed on the diagram in the order that the blood flows around the system, beginning with number 1. Pupils were then required to use paint tools to show where oxygenated and deoxygenated blood flowed around the cardiac system.

Design

Pairs of pupils worked with either the additive parsed animation or the substitute parsed animation, in order to extract verbal protocol descriptions at each new parsed stage of the animation. All sessions were video-recorded for later analysis and to provide a description of the integration process.

Procedure

Subjects were given the written pre-test, completed on an individual basis, three weeks prior to commencement of data collection. Immediately prior to the experiment pupils were informed that they would work with an animation that had been subdivided into sections and were instructed to try to describe what they saw, what they thought it meant and how it fitted with the previous section of information they had viewed. Verbal description was encouraged through prompting such as, What did you see? What does that mean? How does that fit with what you've already understood/ seen? They were aware that the session would be video-recorded. All pupils completed the post tests immediately after the interview. The written post test was completed individually, followed by the computer diagram test, which was done co-operatively. These aspects of testing will be presented and discussed in the second half of this chapter (see 8.4.2.).

8.3.2. Results

The results for this study were taken from qualitative data obtained from video recordings of verbal protocols. Pupils were encouraged to verbalise not only what they could see and understand from each component of the animation, but also to verbalise the links that existed between each section of information, and finally to give a description of the blood flow process. Analysis of verbal protocols therefore consisted of three aspects; *(i)* identification of relevant facets of each section, *(ii)* making referential links between information sections, and *(iii)* describing blood flow.

(i) Identification of relevant facets of each section

No overall significant difference was apparent in the information pupils obtained from each section of the diagram regardless of animation permutation. However, it was evident that certain pieces of information were not identified (again regardless of animation permutation), as follows:

- no pupils noted that oxygenated blood flowed in from the right as well as left lung
- no pupils noted that oxygenated blood flowed out of heart to lower body
- only one pair noted that deoxygenated blood flowed to the right as well as left lung
- specific reference to the blood changes was lacking, despite it being generally noted that blood flowed in oxygenated and out deoxygenated, or vice versa. This occurred most notably in the body, for example, in the body 4 out of a possible 16 references were made to blood changes, whereas in the lungs 9 out of a possible 16 references were made to blood changes.

(ii) Making referential links

There was a significant difference in the number of links made between sections of information according to permutation of animation. A sub set of those using the substitute animation made a total of three of a possible eight links, whereas all eight links were noted by those using the additive animation (see table 8.1.).

Table 8.1. Showing the number of links made between sections of information according to animation permutation.

	Number of subjects additive	Number of subjects substitutive
Link 1	8	
Link 2	4	2
Link 3	2	
Link 4	2	
Link 5	6	4
Link 6	6	4
Link 7	4	
Link 8	2	
total	**34**	**10**

(iii) Blood flow descriptions

Of those using the substitute animation only one (out of eight) pair gave a full accurate description of blood flow, the other pairs missed out either the right lung and lower body or the right lung and upper body in the cycle. Of those using the additive animation three (out of eight) pairs gave an accurate full description of blood flow, including blood changes.

8.3.3. Discussion

The aim of level one of this study was to generate a description of the process of integrating information from a 'parsed' animation of the heart. The parsed animation was presented in two different ways, which generated some differences in degree of success in integrating information. Three aspects of verbal explanation were analysed; *(i)* identification of relevant facets of each section, *(ii)* making referential links between information sections, and *(iii)* complete description of blood flow.

Relevant factors identified from each section of the parsed animation were found to be similar across the two animations, in terms of both accuracies and omissions of information. On one hand this is not surprising given that both animations clearly showed each new section being displayed, thus focusing pupil attention to a particular part of the diagram. However, it is interesting to note that even those using the additive animation were able to maintain their attention focus specifically despite the presence of an increasing amount of the animation information. This suggests then, that contrary to earlier studies in this thesis, that it is not necessarily the amount of perceptually available information per se being displayed on an animation that is problematic for comprehension (Kaiser et al 1992), but the reduction of attention focus that this can cause. This would link with information found in study 1 relating to the kind of task used. Once the problem of attention focus has been addressed the amount of perceptual information per se may be a less significant factor in hindering learning with animation. Focusing attention inherently reduces the amount of perceptual information being attended to, reducing the amount of translation of graphical change, reducing the amount of information needed to be held in memory, and in a cyclical animation allows the learner to reaccess specific parts of the dynamics. This means that an animation could display all fields (at some level of visibility) without dynamic information load, and cognitive overload, if attention focus is relevantly guided.

The omissions pupils made were most likely to be a result of the complexity of the cardiac system itself and the resultant graphics in 2D representation. The 2D format means that some vessels are displayed running *behind* either the heart itself or other vessels. This makes some blood pathways much less perceptible than others, for example, no pupils noted blood flow from the heart to the lower body, and no pupils noted blood flow from the right lung into the heart, while looking at the oxygenated heart section.

The most striking difference between the two animations was in the pupils' abilities to make links between the parsed sections. A minority of pupils using the substitute animation made links between sections at all and those that did made few. All of the links identified for analysis were made by those using the additive animation. This suggests that one animation permutation provided information that was lacking in the other. In the substitute animation each parsed section disappeared when a new one was displayed. This resulted in clearly segregating each section. Conversely, in additive animation each parsed section was added to the previous one displayed, making an explicit link for the learner between one section and the next, and enabling the learner to continue to see the links as previous information was still being displayed.

Descriptions of blood flow between the two animation groups also differed. The majority of those using the additive animation gave full accurate descriptions of the blood pathway and blood changes within the circulatory system. However, those using the substitute animation, although giving accurate descriptions in terms of blood changes and some of the pathways, particular omissions in the cycle were evident, for example, omissions of flow to the lower body or upper body and to the right lung. This confirms evidence that links between pieces of information were more problematic with the substitute parsed animation.

In summary, this case study suggests that when interacting with a parsed animation learners can focus their attention on specific aspects of information enabling them to notice, identify and interpret graphical changes within each section, but that making links between those sections and pieces of information is more problematic when those links are not made explicit within the representational format.

8.4. Study 6

In this study the aim was to collect quantitative data about information integration, overall learning and design issues using the same 'parsed' animations as in study 5, together with a 'control' animation and a 'test control' group. Therefore, three experimental conditions were implemented to assess differences in overall learning according to the design of animation presentation, plus the test control group.

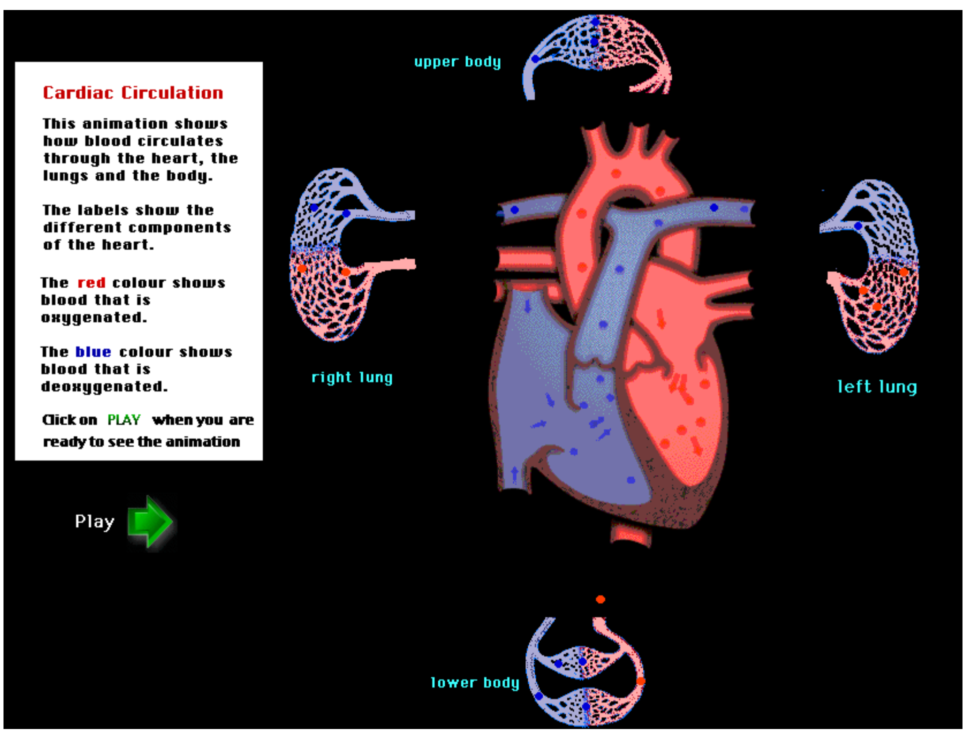
8.4.1. Method

Participants

A total of sixty pupils participated, twelve pupils in each experimental condition, and 24 in the test control group (12 for each half of the test). Participants were different year 8 pupils than those participating in study 5, from the same comprehensive school who were novel to this research. These pupils were again taken from mixed ability science classes, thus providing a distribution of ability across experimental conditions. Thirteen were female (mean age = 13 years 2 months; 158 months, sd = 3.5) and forty seven were male (mean age = 13 years 2 months; 158 months, sd = 3.1).

Materials

Figure 8.3. Example frame from control animation.



The same animations were used as in study 5, but in addition a control animation was used, which was a continuous looping animation without any masking or pre-parsed sections. This animation was similar to that used in the previous experiments (studies three and four, chapters five and six) but was set out on the screen in the same format as the additive and substitutive animations (see CD ROM provided and fig.8.3.).

Pre and post tests were also of the same design as in study 5 (see appendix 12a, 12b and 13). The tests were also given to a control group who did not participate in any experimental condition. This enabled comparison of performance on both test A and B establishing that the questions in each half were similar, and could be reasonably used as a comparative basis for performance. It also enabled questions that were considered to be unique within the test to be given half as pre-test and half as post test to this control group, and could be reasonably used as a baseline measurement of performance on these questions. Total possible scores on each test were as follows: pre tests A and B could score 12; post tests A and B could score 24; delayed post tests A and B could score 24; computer diagram test could score 10.

<u>Design</u>

This experiment consisted of four conditions; *(i)* an additive parsed animation; *(ii)* a substitute parsed animation *(iii)* a control animation, which was a continuous looping of the heart animation, and *(iv)* an overall control group, which completed all pre and post test papers, but did not receive any experimental manipulation.

- Experimental group 1 received the additive parsed animation, where each parsed section of animation was *additional* to the current display, so that increasingly more dynamics were displayed. Pupils had control over when the next section was displayed.
- Experimental group 2 received the substitute parsed animation, where the parsed sections were displayed separately in a prescribed order, so that only one section of dynamics is displayed at one time, thus, each parsed section was *substituted* by another. Pupils had control over when the next section was displayed.
- Experimental group 3 received the control animation in a continuous looping format.
- Experimental group 4 received only the pre and post tests each three weeks apart and served as a control test group.

Procedure

Pupils worked with their allocated animation individually on Macintosh PowerBooks. The layout of the animation mini-program was explained to them prior to its use, and they were given instructions as follows.

Instructions for the animations:

Pupils were informed that the animation showed blood flow through the heart and circulatory system, and how the heart worked; that the animation began with a static diagram of the heart and some text information; that to start the animation they would need to click on a button labelled ‘play’, or in the case of the ‘control’ heart they could press any keyboard button.

For the additional parsed animation:

Pupils were informed of the following: “When the animation plays it will be shown in small sections. If you click the ‘next’ button a new additional section of the diagram will be visible. This continues until the whole diagram is displayed. If you click on the ‘back’ button it will take you to the previous section.”

For the substitute parsed animation

Pupils were informed of the following: “When the animation plays it will be shown in small sections. If you click the ‘next’ button a new difference section of the diagram will be visible. When all sections have been seen the whole diagram will be displayed. If you click on the ‘back’ button it will take you to the previous section.”

Pupils were allowed to work with the animation for a period of time that was considered to be sufficient by each pupil. Time taken was recorded in seconds. No interviews took place in these sessions. All pupils completed the post test immediately after working with the animation. A delayed post test was also completed four weeks later.

8.4.2. Results

The results for this study were quantitative, taken from written and diagram post tests. Scores on all tests were transformed and computed into percentage scores so that comparisons could legitimately be made across different tests. The results will be presented in two sections: the first consists of an analysis of the control test group providing confirmation of reliability of test scores used in subsequent analyses, and the second comprises analyses of the following aspects *(i)* analysis comparing performance according to animation manipulation, *(ii)* analysis comparing learning differences from pre to post tests, *(iii)* analysis of hidden process features, *(iv)* analysis of time taken with each animation manipulation, *(v)* analysis of delayed post test scores.

Section 1

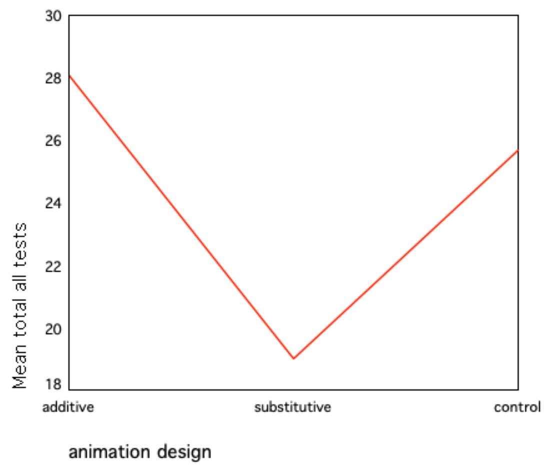
Analyses of test scores were performed to establish that no differences existed between test A and test B, or between pre and post test scores in the group that did not receive any animation manipulation. An independent t-test showed no significant differences between scores for group A tests and group B tests ($p = 0.19$). This suggests that performance on one test could be reasonably compared with performance on the other. A further dependent t-test showed no significant difference in within subject scores from pre to post test in the test control group ($p = 0.10$). This shows that there were no significant differences in the split half of each of the tests given, and that there were no improvement in scores from pre to post test in the group who received no animation permutation. This means, therefore, that any significant differences in scores for groups who received an animation permutation can reasonably be attributed to the animation and is unlikely to be a product of a difference in the split half of the test.

Section 2

(i) Comparison of performance according to animation manipulation

For this analysis the independent variable was animation permutation with three levels; additive parsed animation; substitute parsed animation; and control animation. The dependent variable was the total post test score. A one way independent ANOVA showed significant differences in test scores according to animation ($p = 0.02$). Pupils performed significantly better or worse according to the animation they used. Bonferroni post hoc tests showed that those in the additive group performed significantly better than those in the substitute group ($p = 0.02$), but not in the control group.

Figure 8.4. Graph showing differences in total post test scores according to animation permutation.



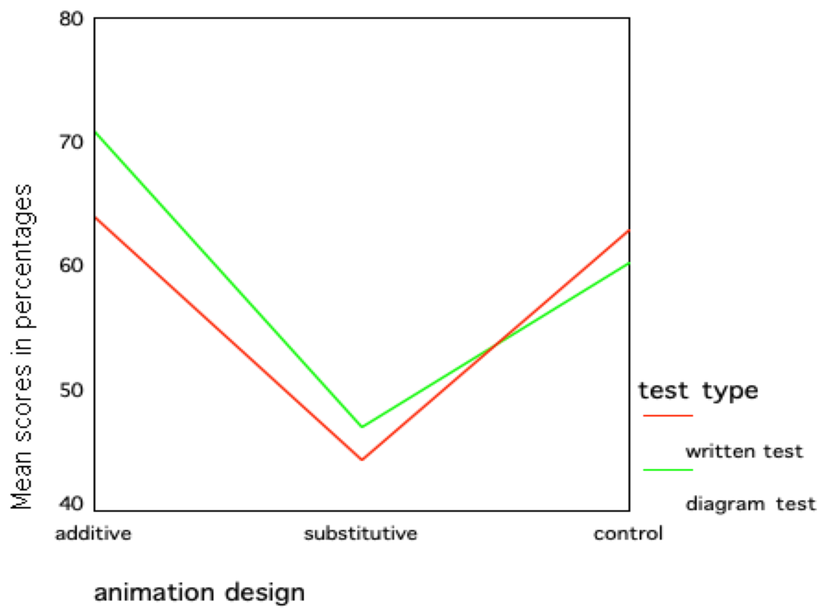
A one way ANOVA looking for differences in performance with the diagram test showed results approaching significance for those using the additive animation (p=0.06).

Table 8.2. Showing means and standard deviations for diagram test

	N	Mean	Std. Deviation
additive	12	12.75	3.98
substitutive	12	8.41	4.96
control	12	10.83	4.13
Total	36	10.66	4.61

A Bonferroni post hoc test showed that this difference was between those using the additive animation and those using the substitutive animation. From the means (table 8.2.) it can be seen that those using the additive animation performed better than those using the substitutive animation on the diagram test. These results follow a similar pattern to results obtained for the written test (see fig. 8.5).

Figure 8.5. Graph showing scores for written and diagram tests according to animation permutation.

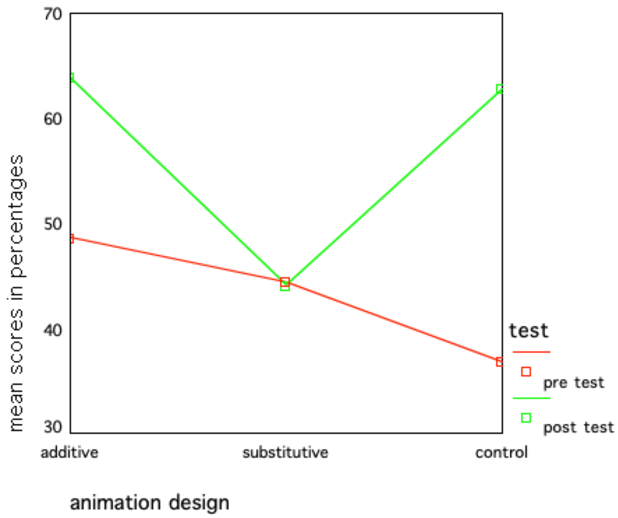


(ii) Comparison of performance between written pre and post tests according to animation.

For this analysis a mixed ANOVA was used. The repeated measures variable was the pre and post test scores, the independent measures was the animation permutation. The ANOVA showed a significant main effect, pre and post test scores were significantly affected by permutation of animation ($p = 0.03$). Significant differences were also found between the pre and post test scores ($p = 0.00$), showing that significant improvement in performance was apparent following animation use. A significant interaction between the two factors ($p = 0.03$), suggests that pre and post test scores differed significantly according to permutation of animation. Those using the additive parsed animation and the control animation performed significantly better following participation with the animation whereas those using the substitute parsed animation did not.

The graph (fig.8.6.) shows that pre test scores were similar across animation conditions, but that the post test score was significantly affected by the animation permutation received. Those in the control and additive condition scored significantly higher on their post than pre-tests, whereas those in the substitute condition scored similarly on the post as in the pre-test.

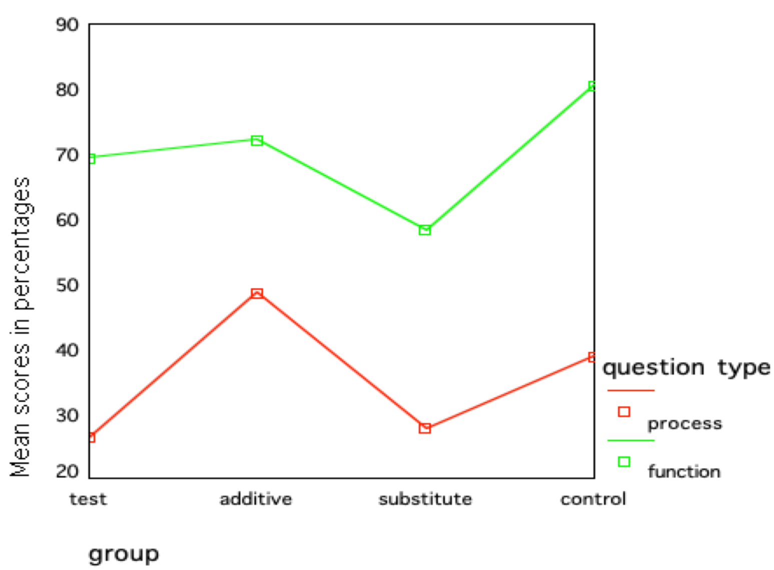
Figure 8.6. Graph showing pre and post test score according to animation



(iv) Analysis of questions on peripheral dependencies aspect.

This analysis was taken from questions 7 and 8 of the post test (see appendix 12b). Overall pupils scored poorly on questions related to function and 'hidden' processes or peripheral dependencies within the cardiac system (e.g. processes such as gas exchange in the lungs and the body). No group scored significantly better than the test control group on either question. Statistical analysis shows that pupils scored significantly lower on hidden process aspects than on functional aspects (p=0.00).

Figure 8.7. Graph showing differences in function and process understanding



(v) Analysis of time taken

A one way independent ANOVA (independent variable – animation permutation, dependent variable - time taken) showed that time taken using the animations significantly differed across groups (p = 0.04). Those in the additive condition spent significantly longer with their animation than those in the substitutive group and the control group. However, it is also important to know if there is a significant relationship between time taken and test scores. A Pearson's correlation between time taken and test scores showed no significance (Pearson's correlation = 0.09, p = 0.59). Therefore, although the time taken with the animation may be significantly different, this difference did not affect the test scores. This means that the difference in scores between permutations can be reasonably attributed to the permutation and not to differences in time spent with the respective animations.

(vi) Delayed post test results

A delayed written post test was administered to participants in all animation groups. However, due to time delay a few participants were not available to complete the test on the day of administration. The scores of these participants were, therefore, removed from the analysis (see table 8.3. for 'n' participants in each condition).

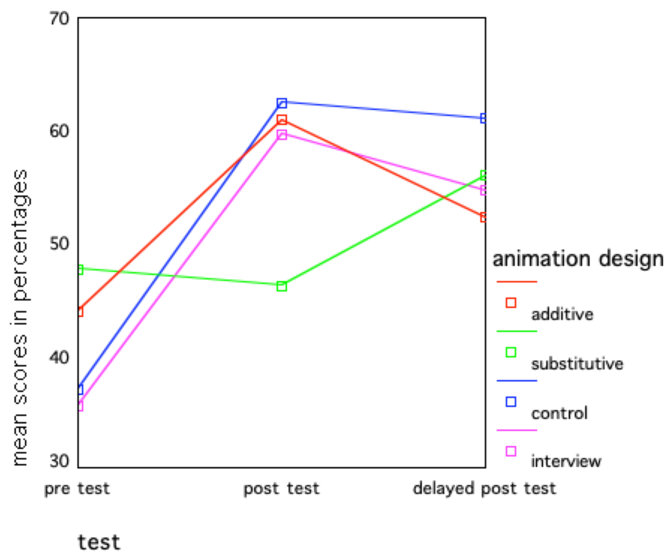
Table 8.3. Showing means, standard deviations and number of participants in each group.

	animation design	mean	standard deviation	N
	additive	43.93	27.91	11
	substitutive	47.72	27.66	11
	control	37.03	24.33	9
	interview	35.55	20.76	15
	Total	40.76	24.67	46
post test	additive	60.98	22.22	11
	substitutive	46.21	22.70	11
	control	62.50	24.91	9
	interview	59.72	27.30	15
	Total	57.33	24.64	46
delayed post test	additive	52.27	30.69	11
	substitutive	56.06	16.70	11
	control	61.11	28.02	9
	interview	54.72	24.33	15
	Total	55.70	24.58	46

A mixed measures ANOVA was performed on the written pre tests, post tests and delayed post tests to analyse any differences across animation groups or tests. The ANOVA showed significant differences in test scores according to time of testing (p = 0.00). A repeated contrast showed that this difference was significant between the pre and post test scores, but not between the post and delayed post test scores (p = 0.00).

A one way ANOVA showed that delayed test scores across groups did not significantly differ. Animation design had no significant effect on delayed post test scores.

Figure 8.8. Graph showing pre post and delayed post test scores across animation conditions.



8.4.3. Discussion

This study elicits information about several aspects of processing animation. The discussion of findings will therefore be presented under specific relevant headings.

1. **Effect of parsed animations on information integration**

The results of this study confirm initial findings from the study 5 (level 1) that understanding was more problematic for those using the substitute parsed animation than either the additive animation or the control animation. Those in the additive animation performed significantly better than those in the substitute animation. In fact the differences in pre and post test scores suggest that the substitute animation provided no assistance to learning at all. Those using the additive animation performed significantly better in the post test than the pre test, whereas those using the substitute animation showed no short term learning benefits. This pattern was similar for both written and diagram tests, suggesting that the test format itself was not indicative of particular results.

The most likely reason for this discrepancy is related to making information links. The case study demonstrated that links between information sections were not identified or noted by pupils using the substitute animation. As the test was designed to focus on linking of information (together with some general conceptual issues) these results confirm that pupils using the substitute parsed animation found making appropriate information links problematic.

There are several factors that could contribute to this result. *(i)* Although on both parsed animations information sections were presented in the same order, the links on the substitute parsed animations were not explicit as in the additive animation. Since the parsed sections remained on the screen, the links from one section to a new section were more explicit, merely due to the fact that the previous parsed section did not disappear. This supports learners in integrating information by providing explicit links between consecutive sections of information *(ii)* The design of the parsing (showing only one parsed section at a time) inherently caused the representation to become a multiple representational format, thus requiring pupils to integrate across representations. Animation maybe shows changes occurring over time more explicitly because of the rate at which diagrams are displayed, but precludes the ease of integrating elements from one representation to another. Without specific reference to linked aspects this makes integration difficult (Narayanan and Hegarty 2000) and adds to the memory load needed to remember information across representations.

It could be argued that there is some inconsistency in this explanation, as both parsed animations were designed in such a way that any parsed sections not yet clearly visible were merely masked, allowing the rest of the animation to be discernible. This design should have removed problems associated with this aspect of multiple representations, as the whole animation was perceptible on the screen. The results, however, may be explained by an attentional problem that could have arisen as a result of parsing the animation. Learners attention is directed to such a degree that they are unable to attend to the masked areas of the animation, or they become unaware of the importance of the rest of the information in relation to the section on which they are currently focused.

In essence, then, it is not only 'parsability' of the representation that is important (Green 1989) but also 'linkability' – facilitating links to be made between relevant parsed sections of information.

2. Effect of the control animation on integration of information

The importance of specific perceptible links is further verified if we compare performance on the parsed animations with that of the control animation. It appears that, although the additive parsed animation was most beneficial in aiding integration, the test results suggest that the control animation provided some facilitation of this process. This may be explained by the fact that the control animation also displayed links between sections, even though those sections were not explicitly segregated. Explicit segregation of animated information may be beneficial in terms of focusing attention and reducing perceptual and memory load, but explicitly displaying links appears to be of higher importance in facilitating understanding than segregation or 'parsing', unless explicit information links are also displayed.

The apparent facilitation in understanding from the control animation may be further explained by amount of prior pupil knowledge in the domain. The pupils in this study had covered some aspects of cardiac circulation earlier in the current school year, so using this animation served at some level as revision. It has been shown that domain experts and novices differ in the way they use external representations, and in the way information is perceived and understood, particularly in terms of meaningful chunking of information (e.g. De Groot 1965, Hinsle et al. 1977, Egan and Schwartz 1979, Ehrlich and Soloway 1984) and in reliance on domain relevant information rather than visuo-spatial characteristics of the diagram (Lowe 1994). The parsed animations focused on domain relevant chunking of information, chunking which the pupils may have been able to achieve themselves when using the control (non-parsed) animation.

3. Effect of animation manipulation on 'peripheral dependencies'

A continuing problem is the lack of awareness and understanding of the relevance of peripheral dependencies or hidden processes (cf. Green 1991 hidden dependencies). These are aspects integral to a full understanding of the system, but are peripheral to the actual displayed system. In this instance the processes of gas exchange in the lungs and the body are inherently difficult for pupils to attend to and link with the displayed cardiac system. This affects their higher level understanding of the concepts of the system. The results of this study suggest that, despite parsing the animation, pupils overall still lacked insight into these peripheral 'hidden processes'. Studies three and four suggested that pupils were able to notice, identify and interpret transformational changes relating to blood flow, but this study suggests that this information is not integrated into the functionality of the system or process as a whole. However, pupils who were required to give concurrent verbal protocols showed better insight and clearer explanations of these processes. This may have been because they were prompted to specifically think about these issues during their explanations, as well as being made aware of the processes through explicit verbalisation of the diagram. Self explanation enables students to infer information from inadequate texts and to construct knowledge that is missing from the text (Chi 1997). This may also be true of learners using animated diagrams, and may be relevant in further research investigating ways in which learning with animation may be enhanced.

4. Implications for learning in relation to previous studies

Although graphical change was not explicitly measured in this study, pupils here showed little difficulty in identifying and interpreting graphical change. This may have been due to a combination of factors; *(i)* Smaller components of information reduces the amount of perceptual information to be attended to at any one time. This not only aids focus of attention on all changes occurring in the displayed section, but (also due to cyclical looping) allows reaccess to information by the learner, who can identify and focus on the aspect they need to 'see' again, without being distracted by peripheral movement. *(ii)* The level of prior pupil knowledge, may have enabled pupils to focus on domain relevant information rather than visuo-spatial aspects of the representation, facilitating interpretation of graphical change. A focus on domain relevance may also have been facilitated by parsing, in that smaller sections leaves less visuo-spatial information on which to focus, enabling parallel focus on domain relevant aspects. *(iii)* The animation in this experiment was continually looped, without exposure restrictions, therefore pupils had potentially more exposure to the animation (and the graphical changes) than those participating in the graphical change experiment (study 4). However, it is interesting to note that those pupils interviewed in the case study (study 5) noticed and identified reasons for changes in blood, including hidden/peripheral processes within the system, better than those in the experimental conditions. These were aspects on which those not 'explaining' scored poorly. As in study 3 (see 6.5.1.) this could have been due to 'explanation' effects on cognition. Explaining again serves to channel processing into thinking about the implications of the information being processed in terms of an overall model of understanding.

5. Implications of differences in time taken with animation

Although there was no correlation between pupils test scores and time spent working with the animation, there were significant differences in the amount of time pupils on average spent according to the permutation of animation used. This suggests that the kind of processing occurring with each manipulation may differ. The design of the representation facilitates or generates different processing strategies or encourages processing of different aspects or amounts of information. The additive animation was on average used for a longer time than the substitute animation and both of these were used for longer than the control animation. Why might this be? There are two possible explanations:

(i) Cognitive effort

The control animation consisted of 'one' representation in the sense that it was not partitioned in any way, and although previous research suggests that information presented in this way is problematic for comprehensive learning due to increased amounts of perceptual information and memory overload due to transience, research has also suggested that learners using animation show a high level of confidence in what they understand (Jones and Scaife 1999) possibly due to the large amount of visual explicitness of the information. The quantity of information and explicitness inhibits information segregation both of graphical change and domain parsing leaving the learner with a cognitive task that is primarily perceptual (visually) rather than requiring learners to invest cognitive effort in 'working out' dynamics and integrating information. The time spent using the animation is therefore minimal. The substitute animation consisted of six parsed sections of the animation. In essence, then, these learners had six representations to view, followed by a whole representation, rather than the 'one' in the control condition. It is therefore, reasonable that more time is taken using this kind of presentation. The additive animation consisted of not only separated parts, but also a gradual increase in display of information, thus, requiring the learner not only to process information from each parsed section, but to explicitly link it to the previous information already present. This gives the learner a further task in processing the information than with the substitute animation. This may explain why those using the additive animation on average spent more time than the other experimental groups.

(ii) Expertise

An alternative, equally valid, explanation is that pupils participating in this experiment had completed the part of the curriculum covering this topic for their current school year. This meant that using the animation was to some degree a revision process. This may have enabled those using the control animation to process the animation without cited complexities of the representational format, and therefore with more ease and rapidity.

6. Implications for learning and design

These results suggest that although parsing the animation into smaller components may be beneficial in reintegrating information, it is not the only important aspect in facilitating integration of information. Relevant links between these pieces of information also need to made, and it is evident that to facilitate integration these links need to be made explicit within the representation. The substitute animation had parsed sections that were segregated such that they became almost equivalent to multiple representations and links were not apparent. By making the links explicit in the representation the learner is not having to integrate separate multiple representations. Designers must therefore be wary of reducing memory or cognitive overload by breaking down the large amount of perceptual information into more manageable sections, unless explicit information links are displayed.

8.5. Conclusion

One property of animation thought to contribute to problematic learning from this kind of representation, is its large amount of perceptually available information. However, this study suggests that it is not necessarily the amount of perceptually available information per se that causes learning to be problematic, but the effect of this on hindering focus of learner attention. If attention focus is facilitated and guided then the consequences of the amount of perceptually available information may be counterbalanced in terms of detrimental effects on learning.

However, although focusing attention appears to minimize problems associated with large amounts of perceptually available information, it results in information being segregated into smaller parts. This means that information must not only be relevantly segregated, but also coherently integrated. This study suggests that in order to achieve or support this, making links explicit is important. This was further supported by evidence of difficulties in perceiving links between highlighted and masked sections of the animation. Thus, learner attention or awareness to relevant links may be significantly affected by the explicitness of those links.

Aspects of the representation that are ‘hidden’ and inevitably less discernable, for example, one object running behind another causing some obscurity, may also hinder a fuller understanding, as does the difficulty in identifying and operationalising processes that are ‘hidden’ (peripheral) but critical to a higher level understanding of the system. These areas could benefit from further investigation. This difficulty in relating peripheral processes to the functionality of the system or process being displayed emphasises a particular place where learners are not always able to make important links between pieces of information.

In summary then, the parsability of the representation is important in relevantly segregating important features of the process, and in reducing complexity through large amounts of visually available information through focusing learner attention, but the linkablity of relevant aspects of the representation is also critical to comprehensive understanding. Understanding is more problematic when those links are not made explicit in the representation.

Chapter 9

General Discussion

9.1. Introduction

9.1.1. Summary of problem space

It can be seen from the literature review on research into the effectiveness of animation, that although many studies have been undertaken in this domain of research, the emphasis has been more on the particular domain or subject population being studied, or focusing on particular variables relevant to animation (e.g. Mayer and Anderson 1991, 1992, Lowe 1994). Although the studies give some valuable information regarding the effectiveness or not of using animation, the theoretical grounding for the research has been mixed, creating results that are difficult to integrate both in terms of cognition and design. However, some researchers have identified the need to analyse properties of representations in terms of their cognitive benefits and disadvantages (e.g. Scaife and Rogers 1996, Green 1989). Thus, research into animated diagrams needs to focus more on the cognitive benefits and disadvantages of the representation, in the context of particular properties or features of the representation.

9.1.2. Summary of aims of studies

This thesis, therefore, set out to investigate ways in which animation could be investigated that would begin to uncover the cognitive effects of animation generally, with the ultimate aim being to identify cognitive components of a processing model of animation. To do this the research was conducted by identifying *(i)* particular features of the representational format as a basis for investigating the potential cognitive effects, and *(ii)* a proposed learning model that would also serve to guide the investigations. The representational properties and their potential cognitive effects were termed Cognitive Dimensions of Animated Representations (CDAR) as they are conceptually similar to Green's (1989) cognitive dimensions of notation, in that they have some relevance to representation (in this case animation) being cognitively beneficial or hindering. The 'dimensions' identified for the research here were primarily related to the explicit depiction of dynamics and the consequent representational effects. The preliminary CDAR selected were multidimensionality, which referred to the amount of perceptual information simultaneously available; transient media, which referred to the evanescent quality of the media; and visual dynamic explicitness through graphical change, which referred to change occurring in different forms, such as translation and transformation.

9.1.3. Overview of studies

Six studies were undertaken to investigate the above aspects of animated diagrams in a learning context. Pupils between the ages of twelve and fourteen learning about dynamic biological processes participated in the studies. The first two studies used comparisons of learning about a dynamic system from either an animated or a static representation, to explore potential benefits and disadvantages of learning with animation, and to discover some properties particular to animation that may affect cognitive processing with this kind of representation. The first study also looked at the effects of structuring versus not structuring information while learning with diagrams. Information from these studies provided a basis for the rationale of the design of subsequent studies investigating more specifically the cognitive interaction with animated diagrams. Studies three and four investigated the effect of graphical change on understanding animation, by assessing pupils' identification and interpretation of different kinds of graphical change occurring in two animations that differed in terms of their multidimensionality. Study 3 was a case study, primarily involving the use of verbal protocols to begin to describe components of a processing model of animation in terms of understanding graphical change. This was followed by an experimental study which looked for progressions in pupil understanding of graphical change over different exposure times to the animations. In this study assessment was based on comparisons of post test scores between exposures to animation, which targeted primarily the identification and interpretation of graphical changes taking place in each animation. Studies five and six investigated integration of information from an animated diagram by exploring the cognitive effects of parsing a diagram in two different ways. Study 5 was another case study focusing on verbal protocol data to provide descriptive information of processing in the context of making links between different sections of information. Study 6 provided experimental evidence of integrating information by comparing cognitive integration using the two differently parsed animations and a control animation. Assessment in this study focused on making links between separate sections of information and enabled analyses of; understanding according to animation design (parsed manipulations), learning gains between pre and post tests; and continued learning benefits from delayed post tests. Collectively these studies provided information about processing of graphical change in terms of identification and interpretation of dynamics, and the effectiveness of animation in facilitating integration of dynamic information.

9.1.4. Structure of general discussion

This chapter discusses the findings from all of these studies in relation to particular aspects of cognition when interacting with animated diagrams (salience, interpretation and integration of graphical change and domain relevant information), as well as the effect of particular identified representational properties and learner properties on cognitive processing (multidimensionality, transience, prior knowledge). Further issues specifically relating to this research will also be discussed (defining complexity, self explanation effects, multiple representation effects). The discussion will then place the findings within the cognitive dimensions of representation analytical framework, and present initial cognitive components identified for a cognitive processing model of animation.

9.2. Understanding graphical change

Graphical change is a predominant feature of animation. Any dynamic event is displayed through graphical changes that take place from one frame to the next in an animation. Research in this thesis in relation to graphical change focused on *(i)* the salience of changes taking place, i.e. the degree to which changes were noticed and identified, and *(ii)* the interpretation of those changes in relation to the diagram domain, i.e. the meaning inferred from those changes. Two types of graphical change were initially identified for the purposes of this research; translation, which refers to movement of an object or entity from one location to another, and transformation, which refers to change in form e.g. size, shape, colour (Lowe 1994). However, another form of graphical change, relevant to understanding, emerged from the research; feature presence, which refers to the appearance or disappearance of an object or entity during the animated display. In order to understand the dynamics depicted on an animation each graphical change needs to be distinguished from another, noticed and identified (salience), and then interpreted (interpretation) in relation to the diagram as a whole. The cognitive effects of the different graphical changes are discussed below in relation to their salience and their interpretability.

9.2.1. Salience of graphical change

Salience may be divided into two parts, noticing a change and accurate identification of the change. This distinction is important as a change may be noticed, but not necessarily accurately identified. As identification is related to interpretation, the accuracy of identification ultimately affects understanding.

The results from study 3 exploring understanding of graphical change suggested that translation change was initially noticed far more readily than transformation change, whereas study 4 suggested that in the early stages of viewing an animation identification of change was primarily transformational (for example, identifying changes of dots from blue to red and red to blue on the heart animation), and although translation change was distinguished, accurate identification was poor. Together these results suggest that translation change may attract the attention of the viewer, so is noticed, but that identifying that change is more complex. Identifying translation change accurately requires the learner to identify the start of the translation, the end of the translation and all of the steps of the pathway between. This may be cognitively demanding as it requires continuous tracking from start to finish, which may be further complicated by potential interruptions from other graphical changes taking place which attract attention, and by integrating the unfolding event across several frames. However, the cognitive demands for identifying transformation may be equally complex in animations where the transformation takes place over several frames. Further research would clarify whether the cognitive demands are a result of temporal aspects of the representation or locational differences involved in the change.

Overall, study 4 (looking at processing across different exposures to animation) suggested that dynamic change was increasingly noticed and identified with increased viewing of the animation. This suggests some evidence that, in relation to salience of graphical change, the cognitive effects of dynamic information load (through multidimensionality) and memory load (through transience) may be counterbalanced by animations that are looped and therefore allow reaccess, at some level, to dynamic information. However, it is unclear from the research here whether all graphical changes need to be identified for comprehensive understanding, nor the level to which looping promotes reaccess. For example, results from study 4 suggest that the rate at which learners continue to notice and identify new changes reduces after only a few loops of animation have been viewed, despite the fact that many graphical changes were left unidentified.

Feature presence was overall problematic to notice and therefore also to identify. Unless highlighted it is unlikely that an appearance or disappearance of a graphical feature will be prominent, especially within a representation that already has simultaneous depiction of other dynamic events. In this thesis the animation where feature presence occurred consisted of some potentially dynamic information being depicted in static format, which necessitated the use of 'feature presence' graphical change. This usage could have been avoided if all dynamic information had been displayed dynamically. This may confirm the cognitive importance that animation displays all fields simultaneously (Stenning 1998). If it is a criteria for a particular animation that a dynamic event is depicted using feature presence, then it may be important to highlight this event, for example with an accompanying sound. The cognitive effect of using sound or verbal narration together with animation was not explored in this thesis, although the benefits of concurrent verbal narration have been continually shown in previous research (e.g. Mayer and Anderson 1991, 1992).

In summary, noticing graphical change and the accuracy of identifying that graphical change may be a function of the type of graphical change itself. It can be seen, therefore, that the distinction between noticing and identifying change is important. Noticing that a translation is occurring is one thing but identifying it accurately is another, and accurate identification is central to coherent interpretation. Whether graphical change is identified as translation or transformation will significantly affect the meaning placed on the event (see 9.2.2.).

9.2.2. Interpreting graphical change

Interpreting graphical change is an important step in both understanding and making inferences from an animated diagram. Accurate interpretation is necessary for coherent understanding. Research from studies in this thesis suggests several things relating to interpretation of graphical change.

(i) There is evidence that interpretation is dependent on the kind of change that is identified as taking place. Whether an event is perceived as translation or transformation will significantly affect the meaning placed on the change. For example, in the respiration animation, carbon dioxide is shown (as a blue circle) moving from the blood cell in the capillary into the alveolar sac, and oxygen is shown (as a red circle) moving from the alveolar sac to the capillary and entering the blood cell. This change was sometimes perceived by pupils as a transformation (the blue circle changing to a red circle in the blood cell), with the resultant interpretation being that carbon dioxide was changed into oxygen. These kinds of misinterpretations may significantly affect the understanding of the processes taking place on an animation.

(ii) The type of graphical change also affects the processing demands needed to understand the change. For example, the meaning of a translation change is integral to the dynamics, whereas a transformational change requires noting the change and then placing meaning on the change. However, each type of change also has certain cognitive disadvantages. Although meaning may be seen as integral to the dynamics in translation change (i.e. this object or feature moves from here to here), the reason for or the function of the movement is not necessarily explicit, and accurate interpretation of the pathway requires continuous concentrated visual tracking. When an animation is displaying large amounts of dynamic information pupil attention may easily be distracted by other dynamic events. Transformation requires understanding the current representation (e.g. red dot representing oxygenated blood), identifying the change (change in colour from red to blue), understanding the new representation of the feature identified (blue dot representing deoxygenated blood), and making an inference about the represented event that has taken place. Processing transformation therefore requires more distinct steps, but a transformation that unfolds slowly across several frames will have the added cognitive steps required for processing translation change.

(iii) Study 3 showed a high level of errors in interpreting graphical change suggesting that making interpretations at an early stage of processing or viewing the animation may be problematic. However, identification and interpretation may be integral to one another, precluding this cognitive progression from taking place later. Looking more closely at this issue, identification and interpretation appear more integral to translation than transformational change. In fact the results from study 4 suggest that accurate interpretation

of transformational change increased with exposure to animation, whereas interpretation of translation change remained poor. As translation change occurred (in thee animation used here) over several frames, the transient nature of animation may have contributed to this, in that information is lost between viewing the start and end of the translation movement. Confusion of translation change was more evident in the heart animation (where there was a higher level of dynamic information) than the respiration animation, which suggests that difficulty in fully identifying or of interpreting translation may be exacerbated by the multidimensionality of the representation, rather than the graphical change per se. Interpretation of graphical change is dependent on the type of graphical change in combination with the dynamic information load. This emphasises the cognitive demands on a multidimensional animation in both accurately and fully tracking translation change, as inaccurate identification of movement will result in false interpretation.

9.2.3. Summary of graphical change

From the studies presented here, there is evidence to suggest that more graphical changes are noticed and identified than are interpreted in the initial stages of viewing an animation. This suggests that the morphological aspects of graphical change are processed prior to the semantic aspects. However, the kind of graphical change itself appears to be instrumental in the accuracy of both identification and interpretation of the change in relation to the diagram, the accuracy also being influenced by the transience of the representation and the level of dynamic information load.

9.2.4. Implications for design

Designers need to be aware of the different kinds of change and the potential effects on interpretation. The clarity of the kind of change occurring is imperative to the kinds of meanings and inferences that may be made. Feature presence should be used with caution, and if deemed necessary may require highlighting in order to attract awareness to this change.

9.3. Integrating information from animation

9.3.1. Relevant review of current studies

Previous research has shown evidence of incremental reasoning during the learning process (e.g. Hegarty 1992, Naryanan and Hegarty 2000), and of the beneficial effects of parsing animation (e.g. Kaiser et. al. 1992). Studies one to four of this thesis also showed evidence of and highlighted the importance of parsing and sequencing information. Study 1 showed that understanding animation was significantly affected by task presentation where structured learning resulted in improved pupil performance. Study 2 showed evidence of patterns of attention focus, indicating that intuitive parsing of gross dynamics may take place. Studies three and four showed that parsing of the dynamics themselves takes place and the importance of this process in understanding graphical change. The value then of parsing and sequencing information was acknowledged and used as a basis for further research in understanding processing of animation in this thesis. To explore integration of information from animated diagrams, parsing at a domain level (see 3.3.1.) was considered appropriate for enabling investigation of the kinds of links made (or not) between different sections of information. Thus, studies five and six used animations that were pre-parsed in two different ways in order to investigate the effectiveness of this kind of manipulation and the kinds of links pupils made to integrate information from the animation. The animations were parsed into six sections. An 'additive' animation showed an increasing number of sections of the diagram until all of the diagram was displayed. A 'substitutive' animation showed only one parsed section at a time, until each section had been displayed.

9.3.2. Research findings

The results of these studies showed several relevant factors relating to cognition and the representational format of animation. The studies showed evidence of improved understanding of blood flow pathways and ability to make appropriate links between information sections on the diagram. In both the exploratory and experimental studies, these factors were most prominent in those using the additive animation, which was more beneficial in terms of making links between the sections of the diagram and in understanding blood flow pathways. There are several possible explanations for these results;

(i) Each section that was displayed on the additive animation remained as another section was displayed, making the links from one section to the next more explicit than on the substitutive animation. The design of the substitutive animation meant that each section was displayed separately, such that no links between each were apparent. Providing explicit links between sections of information may facilitate integration of information. Here there is an example of

explicitness being cognitively beneficial, where the explicitness is in terms of guiding learners to pertinent aspects of the representation in a coherent order.

(ii) The additive animation also appeared to facilitate interpretation of blood flow pathways. This design may also have resulted in more explicit depiction of blood flow (as well as links) as each translation section of flow was shown gradually assisting incremental understanding. Each translation section was also broken into smaller components, which may have been beneficial in terms of focusing attention and fully tracking translation changes, thus, facilitating interpretation of this kind of change.

(iii) As the animations were continuously looped, pupils were able to reaccess the smaller parts of information in the display. Because attention was focused on one particular section of the diagram reaccess may be more cognitively successful than reaccessing information on a looped full animation, where focusing attention on a multidimensional representation may hinder the accessibility of a particular piece of information.

The substitutive animation also had some of these attributes, for example, smaller sections of information, facility to reaccess information, so why did pupils perform poorly when using this particular animation? The display of each section separately resulted in the highlighted sections being multiple representations, requiring pupils to integrate information from one representation to another without explicit links. This not only adds to memory load (having to remember information no longer clearly visible) but also the lack of explicit links makes integration difficult (Narayanan and Hegarty 2000). The highlighted sections of the animation serve to draw attention, which although facilitating focus of attention may simultaneously reduce learner awareness of the importance of the non-highlighted sections in relation to the current section displayed.

9.3.3. Summary

In summary, although explicitly segregating information may reduce the multidimensionality of the animation, thus facilitating attention focus and reaccess to smaller amounts of information, the explicit depiction of links between sections is of fundamental importance in facilitating understanding of the representation as a whole, and indeed appears to also facilitate interpretation of translation change. Parsability of the representation may be cognitively beneficial, but in conjunction with linkability of the representational components.

9.3.4. Implications for design

The findings here suggest that inherent features of animation that may result in complexity, such as, dynamic information load and transience, may be counterbalanced to some degree by breaking down the information display into smaller components. This reduces the dynamic information load and facilitates reaccess (in looped animations), as well as focusing attention relevantly. However, if the animation is parsed in this way, then explicit coherent links between each section must be incorporated, to enable learners to build appropriate models of the system or process depicted. Therefore, not only is it important that the representation be 'parsable', but also 'linkable' (facilitated links to be made between relevant parsed sections of information).

9.4. The effect of multidimensionality

9.4.1. Multidimensionality in this thesis

Multidimensionality of the representation in this thesis referred to the amount of dynamics displayed simultaneously on the diagram. Unidimensional animation would display only one item or 'dimension' of movement at any one time. More than one simultaneously displayed dynamic item renders the animation multidimensional, but the degree of dimensionality of dynamics will inevitably vary from one domain to another, and even within one animated representation. The level of multidimensionality may be determined by the following; *(i)* the particular domain being displayed will have some bearing on the amount and type of dynamics that are displayed, and *(ii)* the level of expressiveness of the representation (the need to display all aspects of a process simultaneously).

9.4.2. Research findings

Study 1 generally showed that explicit depiction of dynamics resulted in confused understanding of flow systems by pupils. One explanation for this could be that animation can result in dynamic information overload, resulting in a confusing presentation of information. On the other hand, it could be argued that the particular design of the depiction of movement used in this study contributed to confused understanding of dynamics. However, further studies with modified animation design also demonstrated that a clear understanding of the flow system was still problematic (e.g. studies three and four). Therefore, it is more likely that clear comprehension of this kind of information may be due something other than the diagram design per se. Dynamic information load (and transience – see below 9.5.) could contribute to this problem, although research on reading graphical change identified possible reasons for problematic interpretation of flow pathways, in that they are represented by translation changes. However, this difficulty may be exacerbated by dynamic information load, in that the resultant increase in displayed dynamics, although more explicit in terms of information, *(i)* increases the number of translations to focus on, and *(ii)* increases the potential level of distraction for the learner, making it more difficult for the learner to focus on any one aspect enabling them to distinguish all dynamic changes occurring, or even know which movement to focus on, when. For example, in study 1 pupils remarked that there was too much movement, too fast.

9.4.3. Potential counterbalancing effects

However, the research in this thesis also suggests evidence of factors which may serve to counterbalance the cognitive effects of multidimensionality of the representation, such as parsing and prior knowledge.

(i) Parsing (also see 9.3.). Results from study 5 suggest confirming evidence of the importance of appropriately focusing attention. Here pupils used an additive or substitutive pre-parsed animation, which showed particular selected areas of the animated diagram at different times, therefore directing and facilitating attention focus. Yet those using the additive parsed diagram performed similarly in relation to those using the substitute parsed animation, despite the fact that the additive parsed animation had increasingly more simultaneous depicted dynamics than the substitute parsed animation. This suggests that it is reduction of attention focus that may be cognitively detrimental rather than just the amount of perceptually available information being displayed on an animation. Thus animated diagrams can be expressive if pupils are guided in focusing their attention to relevant aspects.

(ii) Prior knowledge. Studies three and four showed that pupils with some prior domain knowledge benefited from using animation more than those without. This may have enabled pupils to focus their attention on pertinent aspects of the representation driven by their internal knowledge, thus lessening the potentially detrimental effect of multidimensionality.

9.4.4. Summary

In summary, animation may result in a multidimensional representation increasing the dynamic information load for the learner /user. This can reduce the degree to which pupils are able to focus their attention accurately or appropriately on the dynamics of the diagram, making comprehension harder. However, if attention is focused this cognitively detrimental effect may be lessened. Focus of attention may be facilitated, for example, through particular diagram design, system guidance of pupils learning, differing levels of prior knowledge.

9.4.5. Implications

When using animation to depict dynamic processes or systems, the interaction of multidimensionality and focus of attention in relation to animation is an important issue for designers, teachers and when guiding learner interaction with such representational formats.

9.5. The effect of transience

The form of animation, depicting change through a series of frames, can be described as a transient media rather than a persistent media, in that information is temporary and passes by with the progression of the animation. Although animated diagrams may be looped to show the same set of frames again, the information display remains transient. This means that any dynamic sequences or changes have to be remembered to be integrated with new information. The cognitive effect of this is to increase memory load. The increase in perceptually available information through the level of multidimensionality of the animation will further exacerbate memory load because of the transience of the representation. Straight play-through animation also means that learners cannot reaccess information that has already passed by.

9.5.1. Research findings

The transience of the representation may have contributed to the problems pupils had in accurately identifying graphical change, and specifically the full translation changes that were displayed, such as, blood flow pathways. The problem of the transient nature of animation is apparent, in that information is lost between viewing the start and end of the translation movement. In the animations used here translation changes generally spanned more frames than transformational changes. This means that not only are learners required to track specific changes for longer, but are having to simultaneously track and remember the pathway of the object or entity from previous frames. Were transformational changes to span several frames the same problem may become apparent. Thus, the effects of transience on accurately noticing and identifying graphical change may be to make it more problematic. Study 6, which used parsed animations, suggested that understanding of graphical change was improved over studies three and four. This may have been due to having smaller components of information displayed, thus reducing the amount of information needing to be held in memory, and also to the cyclical looping of the animation, combined with the reduction of perceptual information, enabling reaccess to aspects that needed to be attended to again.

9.5.2. Summary

The form of animation depicting changes over time results in a transient representation of information. This demands that learners hold in memory parts of the animation that have already passed by in order to integrate them with the current and future display. This may increase both memory demands (remembering each change) and cognitive demands (having to integrate changes as more changes are unfolding), making processing of animation complex. Although, some of these problems may be reduced by parsing or breaking down an animation into smaller relevant components of information, provided that links between pieces of information are made explicit, the degree to which transience of the representation affects cognition and contributes to memory load, may also be a function of the frame rate and the frame quantity with which the animation is displayed.

9.5.3. Implications

The design of the particular animation needs to balanced in terms of the potential loss of information between the start and end of either each graphical change or the entire animation itself, and facilitating accurate processing of change by guiding attention, for example, through parsing the animation. However, further research exploring in more detail alternative ways of guiding learning or directing attention, as well as exploring the effect of frame quantity and rate in relation to transience and cognitive processing of animation would be informative.

9.6. Potential effects of prior knowledge

Although this thesis did not set out to specifically measure or compare the effects of level of prior knowledge on reading animation, the circumstances of data collection meant that the potential interaction between level of prior knowledge and performance using animation warrants some consideration. As no specific measurements were taken, the assessment of higher or lower prior knowledge was merely estimated on the basis that teaching about one topic used in this thesis was concurrent with and prior to data collection, whilst the other was not. This meant that not only was it likely that pupils had more domain knowledge for one animation than for the other, but that knowledge was recent and relevant to the experimental domain used in this research.

Overall the findings suggest that those with recent relevant teaching performed better on test scores on understanding graphical change than those that did not. Study 3 and study 4 in the minimum and intermediate exposure to animation showed that those using the heart animation (higher prior knowledge) performed significantly better than those using the respiration animation (lower prior knowledge). More specifically these studies showed that those with higher prior knowledge performed better on interpreting graphical change and on conceptual questions. This particular progression may suggest that salience and interpreting graphical change occurs sooner for those with higher prior knowledge, but that those with lower prior knowledge are not precluded from achieving a similar level of understanding, if exposure to the animation is sufficient. Those with higher prior knowledge reached a similar level of processing the salient features of the animation after an intermediate number of runs, and of processing interpretation after the maximum number of runs. This suggests that processing of salience of graphical change occurs prior to interpretation of the change. Study 6 showed that pupils using a non-parsed animation (information not in smaller sections, no guidance to focus of attention, more dynamic information load) performed similarly to those using an additive parsed animation when integrating information from the animation. This facilitation in understanding from the control animation may also be explained by level of prior domain knowledge.

Research has shown that differences are apparent in the way that experts and novices use external representations, for example, in the way they perceive and understand information, particularly in terms of meaningful chunking of information (e.g. De Groot 1965, Hinsle et al. 1977, Egan and Schwartz 1979, Ehrlich and Soloway 1984) and in their level of dependence on domain relevant information rather than visuo-spatial features of the diagram (Lowe 1994). The level of prior knowledge may have enabled pupils to focus on domain relevant information rather than visuo-spatial aspects of the representation, facilitating interpretation of graphical change. The parsed animations in study 6 also directed pupils to domain relevant chunking of information. A higher prior domain knowledge may have enabled pupils to achieve similar chunking themselves when using the non-parsed animation.

However, although level of prior knowledge may have had some effect on interaction with the animations, the pupils had not reached a level where they could reasonably be termed 'experts', thus, the information gained from these participants was not considered to compromise the findings in relation understanding the cognitive basis for using animation. In fact despite potential differences in level of prior knowledge, pupils showed similar cognitive progressions in terms of understanding graphical change and making links from animated representations. Aspects that seem more pertinent in facilitating processing using animation are the proposed cognitive dimensions of the representation presented and discussed in 9.9.

9.7. Other research findings

9.7.1. Training / expertise

No assessment was made in this thesis of the amount of expertise or interaction pupils had working with animation and /or animated diagrams generally. Previous research has cited the possible need for training in processing graphics (e.g. Peek 1993, cited Betrnacourt & Tversky 2000). Therefore, difficulties of noticing and identifying the dynamics on this kind of representation may be partly a function of familiarity or expertise in terms of reading this kind of representational format. Limited expertise with animated representational format may hamper processing aspects such as tracking moving items, interpreting graphical change. Inexperience and, therefore, unawareness of the required processing may lead to less cognitive attention and effort being applied to these kinds of tasks. Research using differing levels of training with animated representations may inform further about the relevance of animation 'reading expertise' in learning contexts. For example, pupils could participate in clearly guided instruction when using an animation, including such aspects as tracking translation change, practising interpreting different kinds of graphical change and relating these to the diagram as a whole, prior to participating in learning with alternative domain animations.

9.7.2. Self explanation effects

Although self explanation was not used specifically as a tool for eliciting cognitive processing or for assessing learning in this thesis, it is interesting to note that verbal explanation, be it specifically 'self explanation' or 'to another' explanation, appears to have some effect on pupil understanding. More specifically verbal explanation appears to facilitate awareness and understanding of functional aspects of the process that is less apparent in learners who did not externally verbalise their processing. Chi (1997) suggests that explaining brings awareness to the learner of discrepancies in their understanding, which prompts them to revise their understanding more appropriately. It would be interesting in further research to explore the effects of externalising through different kinds of physical interaction with animation, perhaps exploring different outcomes as a result of manipulating the diagram (also see 9.10).

9.7.3. Multiple representations

Although definitions of multiple representation differ, in this research multiple representations refer to the equivalent of multiple diagrams of the same domain, such that each frame constitutes one representation. Consequently, an animation consists of multiple representations to depict the different dynamic changes being depicted. Therefore, learners are having to integrate information from several diagrams or representations rather than one single diagram. Not only do they need to integrate across several representations, but they also need to remember the information to integrate as each representation is not concurrently available with another, and comparisons of differences cannot be made. The studies using the parsed animations took this issue into account and the animations were designed in such a way that any parsed sections not yet clearly visible were merely masked, allowing the rest of the animation to be discernible. This design should have facilitated the making of links between pieces of information displayed in differing explicitness on the diagram. However, it was apparent from the results that these kinds of links were not necessarily made, unless there was visual explicit depiction of appropriately 'linked' components. This suggests that integration of information across different frames may not in itself be problematic, as integration of information appears to take place on different levels. Integration of information across animation frames is taking place on one level when particular graphical changes are identified and understood. Studies three and four showed evidence of this kind of integration. Integration of information takes place on another level when 'parsed' or 'chunked' pieces of the diagram are linked. These two aspects of information integration begin to inform a little about understanding cognitive processing of animation.

9.8. The issue of defining complexity.

Overall the research in this thesis suggests that complexity as defined prior to these experiments is not sufficient. Although multidimensionality and transience may remain features of animation that contribute to a complex representation and impede cognitive processing, in terms of dynamic information overload and memory load, they are not the only dimensions of complexity to be taken into account when processing animated diagrams or indeed any diagram.

The form of graphical change itself may be cognitively complex, in that each type of graphical change demands different kinds of processing. For example, translation change requires consistent tracking over time, transformational change requires mapping of meaning of, for example, colour changes or changes in size onto real world events, feature presence demands noticing whether or not a particular item is present at any one time. The cognitive demands of understanding graphical change may be further enhanced by the level of dynamic information load (multidimensionality of the particular animated representation), which may prematurely distract attention, and transience, which may facilitate potential attention distraction.

Complexity may also be defined in terms of expertise, referring to both prior knowledge and experience with the representational format. The knowledge or perception already present cognitively influences the way the external representation is perceived and interpreted. The level or even type (general or domain specific) of ‘internal’ cognitive resources available to pupils when interacting with the external representation, may serve to reduce the effect of the complexity of animated diagrams in various ways, for example, helping to direct attention to relevant aspects of the diagram, aiding accurate interpretation. However, it may also be the case that inaccurate prior knowledge results in misidentification of graphical change and misinterpretation. This emphasises the importance of clarity of the representation in terms of cognitive dimensions of the representation as defined below (see 9.9).

Expertise with animated diagrammatic format may also serve to reduce some of the cognitive complexities inherent in animation. Practice or training with reading this kind of representation may facilitate focus of attention, aiding differentiation, identification and interpretation of graphical changes, direction to relevant aspects, making links between different pieces of information.

9.8.1. Summary

Although potential cognitive complexities from inherent features of animation are apparent, there may also be factors that serve to counterbalance these effects facilitating benefits from the advantages of explicit dynamic depiction in learning about dynamic processes, such as parsing animation, directing learner attention, providing explicit information links.

9.9. Cognitive dimensions of representation

Cognitive dimensions of representation were described in chapter three as properties specific to animated representations that affect the way that information is processed. This term was adopted for this thesis from Green's (1989) cognitive dimensions of notation on the basis that it provided an appropriate conceptual framework from which to explore the cognitive benefits and disadvantages of animation. The findings from the studies in this thesis point to certain features that could be termed cognitive dimensions of the representation, that are not only features related to the representation itself, but also features related to cognition (where the features of the representation interrelate with relevant cognitive features).

Proposed cognitive dimensions of representation:

(i) Visibility; which refers to the degree to which the representation facilitates noticing of all graphical changes (translation, transformation, feature presence).

(ii) Identifiability; which refers to the degree to which the representation enables differentiation between types of graphical change, i.e. facilitates the distinction between translation, transformation and feature presence.

(iii) Trackability; which refers to the degree to which the representation facilitates tracking of changes over time.

(iv) Interpretability; refers to the degree to which the representation facilitates the placing of appropriate meaning on graphical changes.

(v) Parsability; refers to the degree to which the representation facilitates segregation of information into smaller coherent components, be they a dynamic change, or a domain relevant section of the diagram.

(vi) Linkability; refers to the degree to which the representation makes explicit the links between appropriate sections of information.

These dimensions have been identified as important dimensions of animation for learner interaction, but several (if not all) will, no doubt, be determined by other factors, such as; the dimensionality or the amount of simultaneous graphical changes taking place contributing to dynamic information load; the transience of the representation in terms of the speed at which graphical changes unfold and pass by, contributing to memory load; and the degree to which the representation facilitates focus of attention.

9.10. Cognitive model of processing animation (see fig. 9.1.)

In summary of the findings from this research on processing animation, the cognitive demands may differ according to the level of dynamic information load, transience and the explicitness of graphical changes, smaller domain divisions and links between these information sections. Noticing, identifying and interpreting graphical change appear to have different cognitive demands according to the type of graphical change. For example, identifying transformational change seems less cognitively demanding than translation change, whereas interpreting transformational change seems more cognitively demanding than translation change. Smaller domain divisions within the representation may be cognitively beneficial not only for making interpretations of graphical changes but also for making links between different pieces of information, if those links are made explicit. On the basis of findings in this thesis the following stages in processing animated diagrams of dynamic processes are proposed:

9.10.1. Visibility demands

a) Parsing of dynamic change.

The processing of graphical change consists not only of noticing dynamic changes taking place on the diagram, but also the identifying of the kinds of graphical changes taking place.

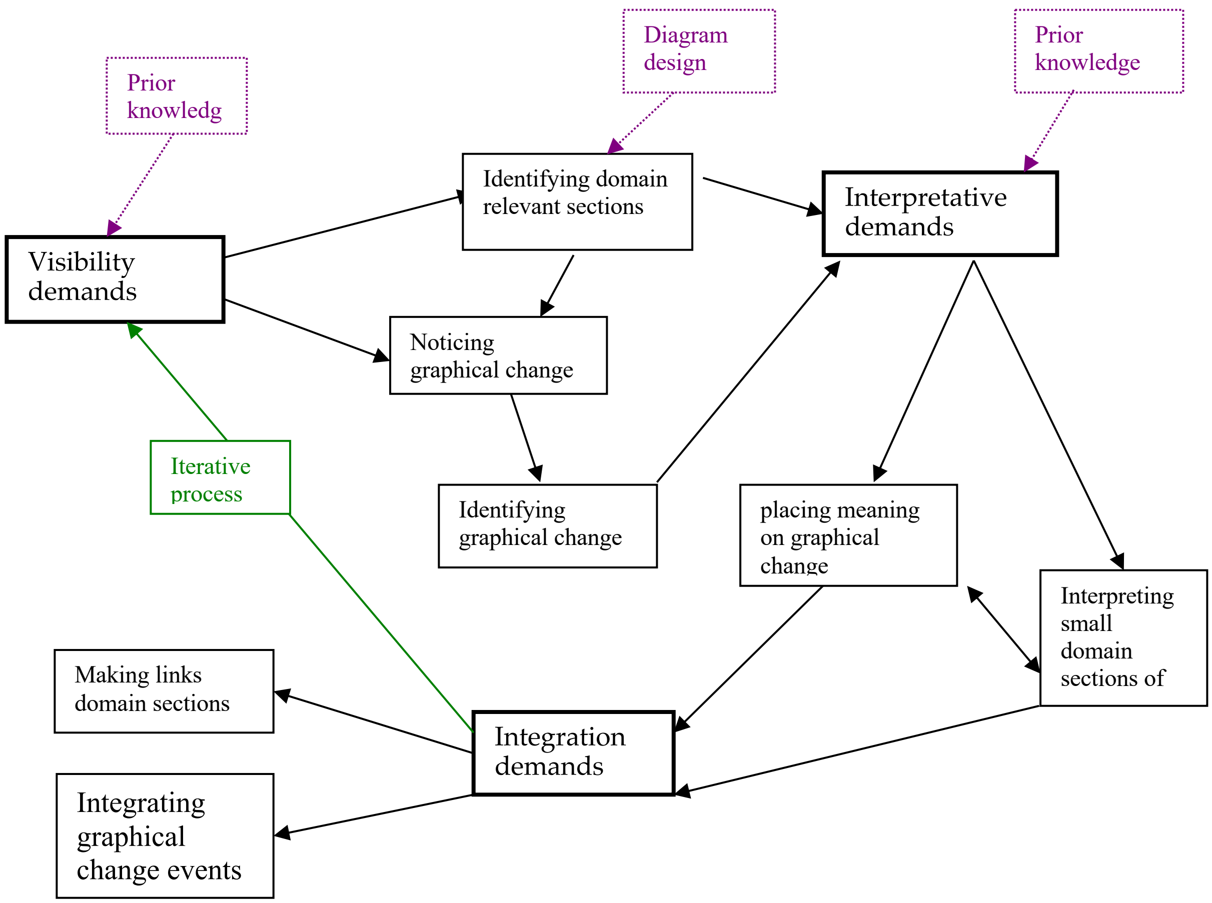
(i) Noticing graphical change basically refers to an awareness of the learner that a dynamic change or event has taken place. This is a general observation about each change that is no more specific than knowing it has happened. However, the likelihood of the change being noticed may be a function of (amongst other things) the type of change. Detailed noticing of graphical changes may be affected by the dynamic information load within the animation (the more changes occurring the more difficult it is to notice accurately) and by the transient nature of the representation, which potentially contributes to loss of information from the start to the end of a change.

(ii) Identifying graphical change refers to distinguishing the particular type of graphical change (transformation, translation or feature presence) as this is essential for accurate interpretation of the representation. Accurate identification may also be affected by transience and dynamic information load.

b) Parsing domain sections

Processing animated information comprises collecting information from smaller domain relevant sections of the diagram, which includes integration of both animated (graphical

Fig. 9.1. Example cognitive model of processing animation



change) and static components of the diagram. Facilitating this process for learners (generally novices to the domain) will be a function of the diagram design itself (e.g. explicit parsing of the diagram) or learner guidance provided.

9.10.2. Interpretative demands

Accurate interpretation is necessary for a coherent understanding of the system or process depicted. The interpretation that is placed on the graphical change is dependent on the type of change that is perceived and identified, and on the amount of detail of the change that is observed. For example, understanding may be incomplete if only part of a translation change is viewed. The research in this thesis suggest that the interpretive demands differ with type of graphical change. Making interpretation of transformation changes requires identification of the change (e.g. change in colour, change in size, change in shape) and placing some coherent meaning on the change depicted, recognising the meanings between the differing states, whereas the meaning of translation change is integral to the dynamics themselves.

9.10.3. Assimilation demands

Assimilating information and/or making links incorporates the linking of information across smaller relevant domain sections of the diagram, as well as linking the dynamic events with the static features of the representation, and is important to building a coherent model of the process being depicted. Research here suggests that integration of information may be facilitated by provision of explicit links within the representation.

Above several particular stages that the learner might go through to process animated information have been proposed, but these stages are unlikely to be as distinct as the proposal of stages appears to indicate. It is likely that much more parallel processing is going on, such that a graphical change is noticed and interpreted at a similar time and possibly integrated into previous knowledge or another piece of information from the diagram. It is likely that a complete model is built in this way rather than in distinct separate stages of noticing, identifying, interpreting, parsing, and making links. Evidence from the studies in this thesis support this since not all dynamics were noticed or interpreted, but some understanding and integration still occurred (cf Beaugrande 1987). The model also includes proposed effects of other variables according to findings in studies in this research. These variables are shown in a different colour (violet) and surrounded by a dashed box. Although significantly more research is necessary to confirm, expand and develop any proposed cognitive model of processing animation, the research in this thesis has made a small step in attempting to pinpoint more specifically the ways in which learners cognitively interact with animated representations.

9.11. Generalisation of research

One of the problems cited in chapter two regarding research into the benefits of animation was the lack of continuity underlying the varying research studies in terms of theoretical frameworks. This makes generalisation of results and findings outside the individual studies problematic. This research attempts to use a framework for analysing animation that focused on representational properties and their cognitive effects. This means that these same representational properties in other domains are likely to have similar cognitive effects. This may not apply only to animations of dynamic processes, but could also apply to animations showing steps in, for example, solving a problem. Suppose that animation was being used to show the progression of solving a problem this would require learners to understand various appropriate steps to be taken to reach a conclusion or solution. Although there might be differences here in terms of whether the learner has to understand a dynamic system or just learn/understand the steps to solving a problem, there are no differences in terms of the processing required when using the animated form of a representation. When steps to solving a problem are depicted using animation the learner is still required to notice and identify changes in the representation and infer some meaning from the changes in order to understand how the problem is being solved. Thus, a more abstract analysis of how the representational properties of animation affect cognition should facilitate generalisation of findings to other domains using animation.

9.11.1. Implications for cognitive processing model

The cognitive processing model proposed here is merely a beginning in identifying cognitive components of a model and ways in which these components may be affected by representational properties and learner properties. This research may serve as a basis on which to build a more comprehensive picture of cognition with animation through further analysis using similar frameworks. The use of similar frameworks would facilitate the integration of findings from other domains or instances where processing animation takes place.

9.11.2. Implications for designers and teachers

The findings in this thesis point to particular aspects of animation primarily in terms of its visibility, interpretability, and linkability that are important for the learner. This can inform designers on particular ways in which this representational format may be designed to facilitate understanding of dynamics by being aware of the importance of the dynamic components and movements being 'cognitively available' to the learner, the effects of multidimensional dynamics and transience. It may also inform teachers in similar ways, in addition to enabling them to be aware of the importance of focusing pupil attention appropriately in relation to the particular learning task at the time.

9.12. Future research

The studies in this thesis have investigated specific aspects of processing animation, and therefore covered a limited area within a large problem space. The work has also uncovered aspects of design and methodology that may have had an impact on some of the conclusions that may be drawn from the studies, as well as bringing to light areas of research that deserve further exploration and examination.

9.12.1. Limitations of methods

Exploring cognitive processing of animation is not a straight forward process. Different kinds of data and study conditions will elicit different kinds of information. Therefore the research in this thesis has used both qualitative and quantitative data, requiring both descriptive and experimental methodologies, in an attempt to achieve the most comprehensive information regarding processing. However, it is also important to work within the environment relevant to the research, thus studies were carried out in schools willing to participate. Needless to say this in itself can create drawbacks, such as time limitations for visiting school, time limitations working with each pupil, uniformity in terms of teaching across the several weeks needed for data collection, thus resulting in unexpected confounding variables as found in studies three and four (teaching of one research domain but not the other). Time limitations also have an impact on the assessments that can be undertaken. Assessments needed to be tailored to time limitations and therefore may not have been as comprehensive as would be ideal. Question sets targeted primarily aspects investigated in each study, therefore were not broad enough to make any comprehensive conclusions about overall conceptual learning from animation. Another issue may be that the type of assessment may affect the learning outcomes obtained, as in these studies pupils were having to transfer knowledge learned from animated representations but elicited through written or static diagram assessment. Although comparison of diagram versus written in study 6 showed no differences in performance, the use of animation to elicit knowledge may have produced some different results. Aspects such as these may be modified in future research samples.

9.12.2. Future directions

As a beginning to describing a cognitive model of processing the research here aimed to provide a basis for further research that would build a more comprehensive picture of cognitive processing of animation. However, a few particular areas of future research are outlined here.

(i) Temporal depiction

One main feature of animation is that depiction of changes through sequences of still images inevitably depicts an order of events within the representation. Not only does animation mean that motion is depicted visually more explicitly, but also that the temporal aspects of the process become overt. Thus, temporal sequences are displayed, not only showing time for each dynamic event, but also relational temporal aspects. In addition, different tempos can be used to depict the dynamics and may elicit different kinds of comprehension. Thus, explicit depiction of any differences in relational rate of change or motion can be displayed. Although this feature is important in the use of animation it is not specifically addressed in this research, as several aspects of temporal depiction, such as, understanding of time sequences, relational timing of events, the effect of different speeds or tempo, including frame quantity and frame rates, would provide more information for a cognitive model of processing.

(ii) Additional cognitive dimensions

In Green's (1991) research into cognitive dimensions of notation several dimensions have been defined and additional dimensions continue to be explored in relation to that research (e.g. Blackwell et. al. 2001). Some of these may be identified as having similar properties to potential dimensions of animated representations, as well as new dimensions that may emerge through further research. Other dimensions may emerge with differing learner tasks, or learner interactions, particularly if interactivity (physical) was available with the animation. For example, certain dimensions may facilitate or encourage user control over the information in terms of choice of order of depiction.

(iii) Interactivity

In the studies used in this research learners had no guidance from the programme to other associated pieces of information, nor were they able to manipulate anything that happened on screen. This kind of manipulation level could vary from basic stop/ start, alter speed to putting in valves, altering the blood flow to see what would happen, or building their own circulation system (e.g. as interactivity on the cardiac tutor, Woolf and Hall 1995). Different interactivity levels may have resulted in different understanding. Thus investigation into the value of different kinds of interaction with the animation for learning and understanding dynamic processes would be useful. Kirsch (1997) has proposed a "decision model of interaction". This model incorporates much more clearly the idea that interaction is an ongoing dynamic and changing activity that is moulded and defined by the users' previous actions, steps and outcomes. In practical terms this means that information be designed in such a way that affordances are created for the learner giving coherent direction on what actions to take at particular points in the learning environment, such that somehow salient pathways of learning or searching or interacting in relation to the learners' previous actions, are made evident. In addition Kirsch (1997) proposes additional ways of interacting which he terms 'reshaping the cognitive congenialist of the environment'. This means that effective ways of providing information are implemented that, for example, help the learner to decide what to do next, or that demonstrate salient links between related concepts by highlighting those aspects together perhaps through colour or through fading and highlighting related pertinent areas of the animation. Functionality links may also be identified in this way. This concept may also tie in with the concept of cognitive dimensions or properties of animated diagrams, by exploring whether there are cognitive dimensions that could be classed as 'cognitively congenial'. Are there dimensions that provide effective ways for making information salient, or helping learners to make appropriate links?

Another dimension of interactivity is that of construction by the learner. Previous research has shown that interpretation of representational displays may be aided by learners constructing external representations, as the process of construction forces the learner to be more aware of their interpretations (e.g. Cox and Brna 1995, Brna 1996). This effect may be similar to the effect of externalisation that occurs with the self explanation phenomena (Chi 1997). The act of self explanation itself may not be practical within a school system, nor necessarily in the context of using computers for learning, but it might be interesting to explore further the ways of gaining similar effects using other cognitive methods, such as constructing dynamic processes using animation, with facilities to run simulations of the process from the constructed animation.

*(iv)*Expertise has been shown to affect processing in problem solving situations and when using external representations to support learning or understanding (e.g. De Groot 1965, Lowe 1996, Brna et. al. 1997). Expertise may be in terms of prior knowledge or expertise with using the particular representational format, both of which will influence the ways in which learners interact with animated diagrams. It would therefore be interesting to explore ways in which these variables affect the processing of animated information as found in these studies, showing in what ways each aspect influences cognitive interaction with animation.

*(v)*Cognitive style

Using animated diagrams as a learning tool is a highly visual medium, and may therefore be used in differing ways by students with different learning styles or different cognitive styles. For example, cognitive styles have been shown to affect learning with different representational formats and different tasks (e.g. Riding and Cheema 1991, Riding and Douglas 1993, Riding and Rayner 1995), spatial ability has been shown to influence understanding involving inference of dynamics (e.g. Hegarty 1992). Thus, other research findings suggest that the value of using such representations as animation to depict dynamic processes may be affected by individual differences in learning or cognitive style and learning strategies.

(vi) Design issues

Finally, worthy of mention is the effect of various design issues. Ways of depicting particular kinds of information can be achieved through different graphical representations, for example, representing flow of fluid may be depicted by use of arrows or dots or colour change. The effectiveness of each manner of expression for understanding may differ. However, the particular graphical design may also affect salience of graphical change and subsequent interpretation of graphical change. Again these issues were not specifically explored in this thesis although some design issues regarding salience an interpretation of graphical change were found (e.g. see 7.5.). It is apparent that research uncovering some design issues result in conflicting design ideas. For example, Stenning (1998) proposes that in animation all fields should be determined simultaneously, whereas Milheim's (1993) guidelines suggest animation should be simple, but sufficiently complex to convey the important information within it. However, neither the terms ‘simple’ nor ‘complex’ are defined, and the concept of definitive ‘important information’ is somewhat misleading. What is important to one learner may not be to another, and if an animation is simplified by reducing some of the information, how do we know the effect of this on the kinds of inferences learners make? It seems that some of the design issues are intricately tied with several other issues, such as, interaction, learner knowledge, learner diagram expertise, and future research in this area must work to build on findings in a systematic kind of way.

9.13. Conclusion

In order to carry out the research in this thesis a conceptual framework was developed for evaluating the cognitive value of animated diagrams. The framework was developed with the concept of abstraction and generalisation in mind, to overcome the problems of the integration of findings from previous studies investigating the use of animation for learning. It was successful in enabling identification of particular features or properties of the representation, as well as particular features or stages pertinent for learning. This meant that particular aspects of this kind of representation (animation) could be examined and evaluated such that they could provide information for a cognitive model of processing as well as inform both design and education in terms of both teaching and pupil learning.

A main benefit of this kind of conceptual framework is that it can be used to generalise to other animated diagrams in other domains, as well as to other user populations. Furthermore, the application of this framework for further research may uncover additional properties or features of animation (or features that may emerge in different domains) and learning enabling further analysis that would give added information about the effectiveness of animation and the design of such representations in the future.

This framework is also valuable as a basis for more extensive research on animated diagrams, as the abstract level from which it works will enable analysis of more diverse aspects of animated diagrams, such as, investigating the effectiveness different types or levels of interactivity with animated diagrams for learning. In this context new properties or features of the representation and/or the learners interaction with the representation may emerge, which in turn may generate new cognitive dimensions of animated representations.

In summary, the conceptual framework developed here has many uses and benefits. Firstly, it lends itself to generalisation at a level that previous research on animation does not. Secondly, it is potentially valid in other domains and in other user populations. Thirdly, it is valuable for researching and evaluating other aspects of using of animated diagrams, such as the effectiveness of interactivity with animation, as well as learner aspects, such as individual differences. Finally, it provides a generalised framework for further research, enabling more valid comparisons across studies, more cohesiveness in their findings resulting in a more comprehensive understanding about the effectiveness of animation for learning and informing, as well as a clearer picture on how best to design and implement the use of this particular form of representation.

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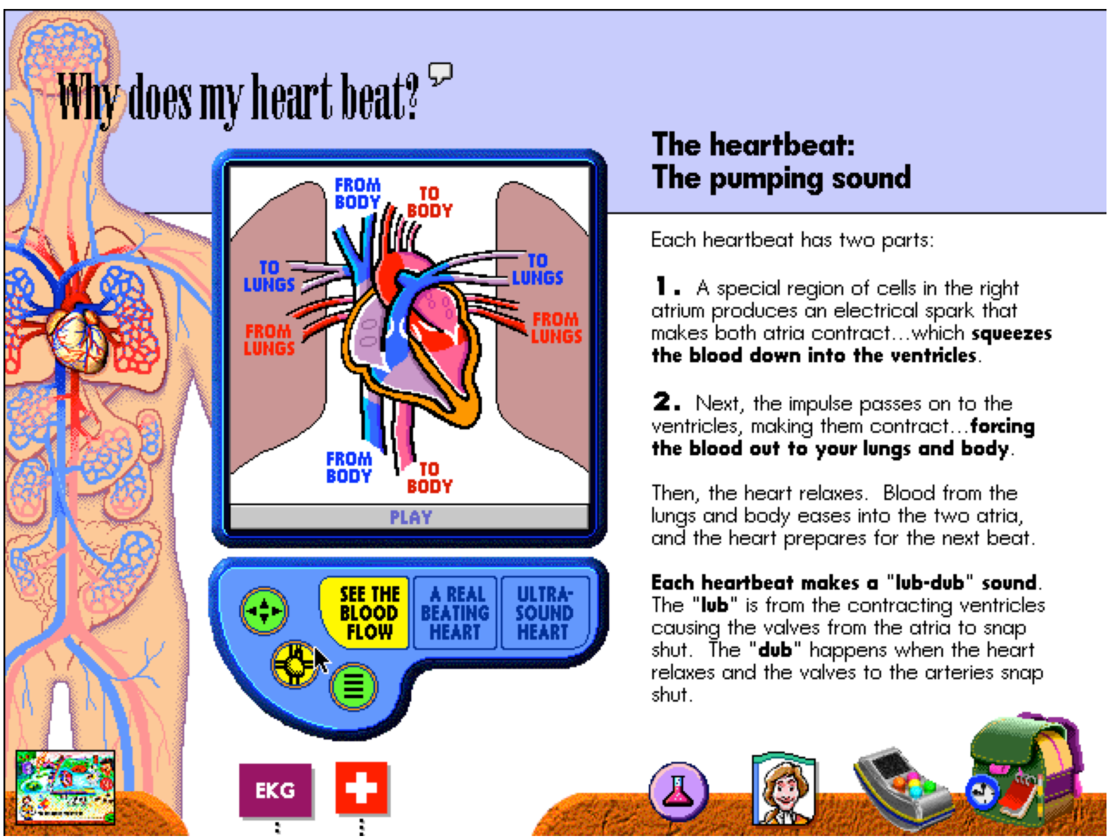
Appendices

Appendix 1

(study 1)

Animated information (example page with video showing blood flow)

see “What’s the Secret” CD ROM from 3M learning software for full animation.



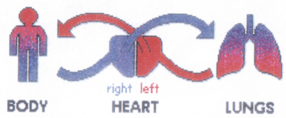
Appendix 2

Static paper information (two pages)

(Study 1)

page 1

Circulation of blood through the heart



The **right side** (tinted blue) takes in "stale" blood returning from your body.

This blood ●●● has **less oxygen** - your body used some of it. It flows through the right side of the heart on its way to your lungs.

The **left side** (tinted red) takes in "fresh" blood returning from your lungs.

This blood ●●● is **rich in oxygen** - it's just come from the lungs. It flows into the left side of the heart, then is pumped out to your body.

Your heart is divided into right and left sides. Each side has an **upper chamber**, or **atrium**, and a **lower chamber**, or **ventricle**.

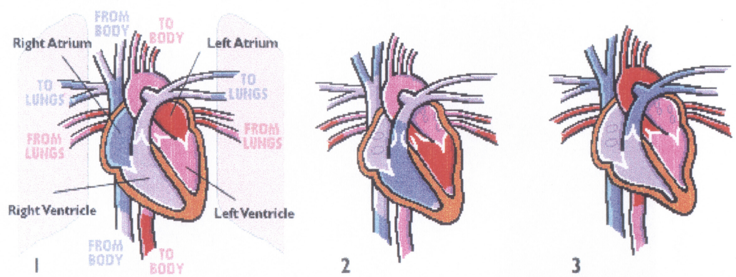
Each atrium is connected to its ventricle by a special **one-way valve** that keeps the blood moving one way.

Each side of your heart is separate. A wall of muscle acts as a barrier. Blood does not flow directly between the two sides.

Blood enters the heart through an atrium. The atria (plural for atrium) are smaller, have thinner walls and act as "collection tanks."

Blood leaves the heart from a ventricle. They are larger and more powerful. They are the heart's "pumping stations."

2 A special region of cells in the right atrium produces an electrical spark that makes both atria contract…which **squeezes the blood down into the ventricles**.



1 Each heartbeat has two parts:

The heart relaxes. Blood from the lungs and body eases into the two atria, and the heart prepares for the next beat

3 Next, the impulse passes on to the ventricles, making them contract…**forcing the blood out to your lungs and body**.

Illustration of Blood Flow through the Heart

Appendix 3

Tasks

(Study 1)

(i) Open task

For static paper condition.

<u>Blood flow through the heart</u>

You have a friend Iona Heart, who is taking a first aid exam. Iona needs to know how the blood flows through her heart. In fifteen minutes use the diagram and information provided so that you can explain to Iona;

- how the blood flows in through and out of the heart.
- about blood that is rich in oxygen, and blood that has less oxygen.
- about the different chambers of the heart.

For animated CD ROM condition

<u>Blood flow through the heart</u>

You have a friend Iona Heart, who is taking a first aid exam. Iona needs to know how the blood flows through her heart. In fifteen minutes use the CD ROM provided so that you can explain to Iona;

- how the blood flows in through and out of the heart.
- about blood that is rich in oxygen, and blood that has less oxygen.
- about the different chambers of the heart.

(ii) Structured worksheet for static and animated conditions.

Heart Worksheet

Using the information provided, find out about the following, and complete all sections.

1. Your heart is divided into left and right sides.

a) Which side has blood that is less in oxygen?...

b) Which side has blood that is rich in oxygen?...

2. Answer the following about the heart's chambers.

a) How many chambers are there in the heart?..

b) Which chambers receive blood?...

c) Which chambers pump blood?...

3. Your heart receives and pumps out both blood that is rich in oxygen and blood that has less oxygen.

Answer the following about blood that has less oxygen.

a) Where does blood that is less in oxygen come from?.................................

b) Which chamber of the heart does this blood enter?....................................

c) Which chamber does it flow to next?..

d) Where is blood that has less oxygen pumped to?..................................

Answer the following about blood that is rich in oxygen.

a) Where does blood that is rich in oxygen come from?.................................

b) Which chamber of the heart does it enter?..

c) Which chamber does it flow to next?...

d) Where is blood that is rich in oxygen pumped to?.....................................

4. The blood flows around your body, heart and lungs in a continuous circular pattern. Show that you understand the order of blood flow by filling in the empty brackets using numbers 1 to 8, starting with ....(*1*) *from body*;

( ) to body ( ) to right ventricle

(*1*) *from body* ( ) to left ventricle

( ) to lungs ( ) to right atrium

( ) from lungs ( ) to left atrium

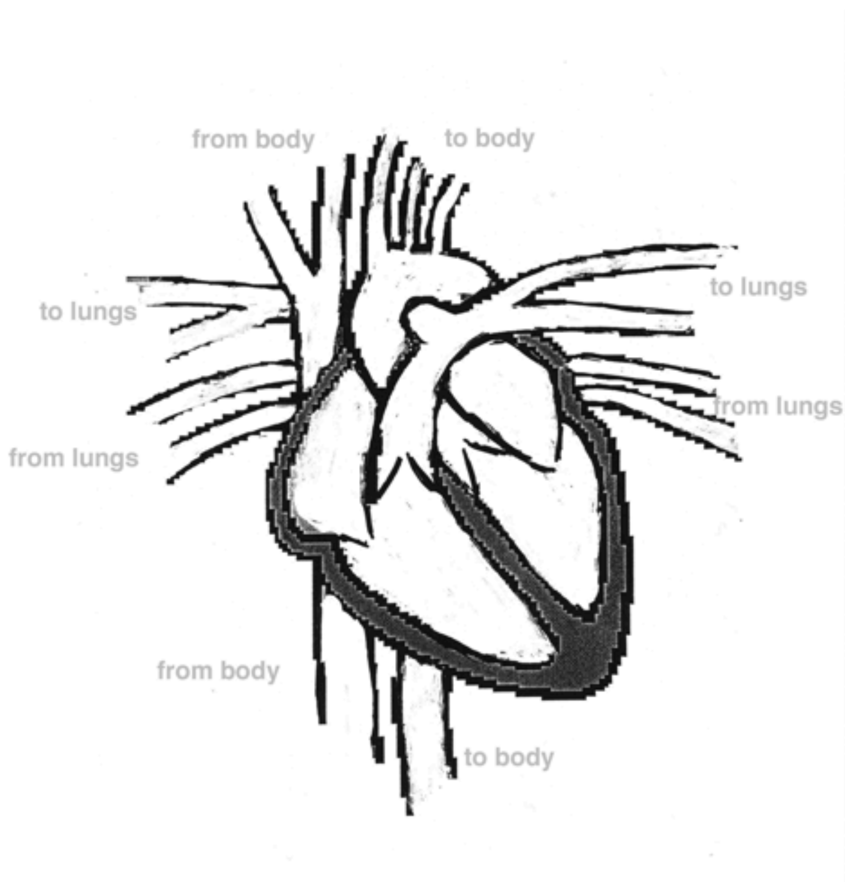
5. Draw your own simplified diagram of how the blood flows through your heart, a diagram that would help you to remember the sequence and direction of flow.

Appendix 4

Test

(Study 1)

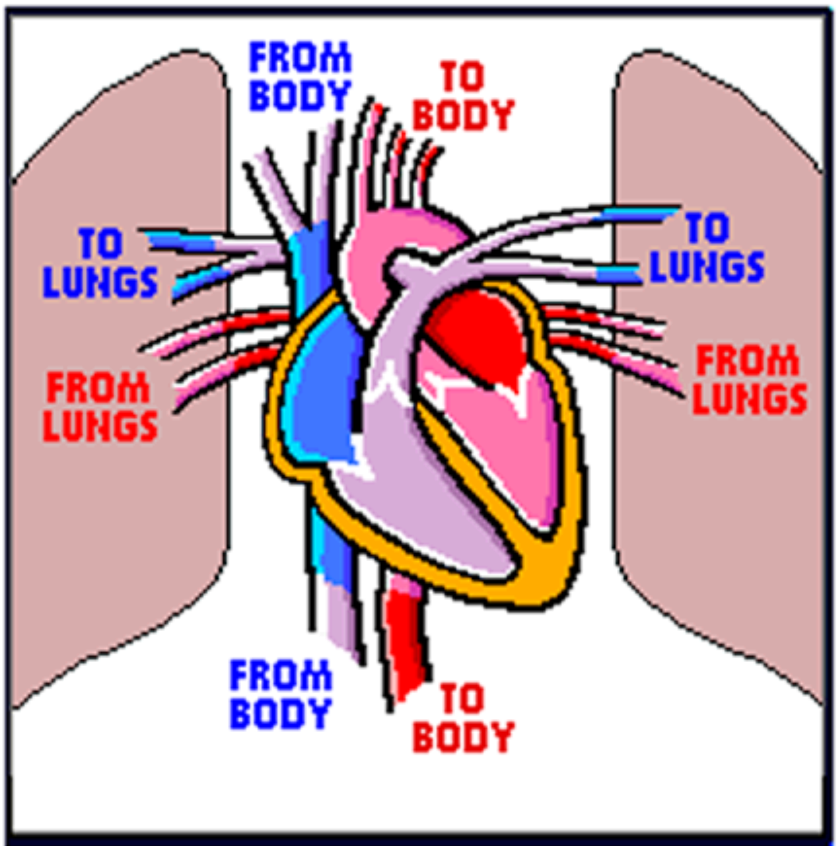
Example of test diagram.



Appendix 5

Animated information – **example frame from CD ROM**

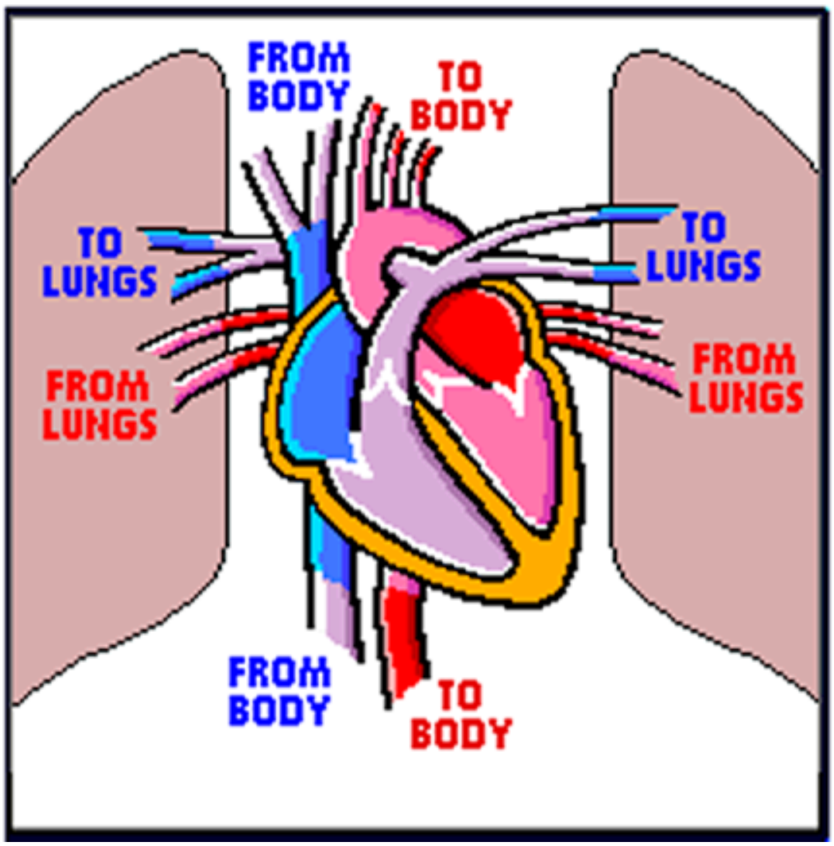
(Study 2)



Appendix 6

Static paper diagram

(Study 2)



Appendix 7

Tests

(Study 2)

(i) written

Please try to answer the following questions;

1. What do you think is the main function of the heart?

2. a) How many chambers does the heart have?

b) can you name any of them?

For the following three questions please tick the appropriate answer.

3. a) where does oxygenated (rich in oxygen) blood flow from?

LUNGS............ BODY................

b) Where does it flow to?

LUNGS............. BODY.................

4. a) Where does deoxygenated blood (less in oxygen) flow from?

LUNGS............... BODY...............

b) Where does it flow to?

LUNGS................ BODY...............

5. a) Through which chambers does the blood enter the heart?

UPPER.............   LOWER.............

b) From which chambers does the blood leave the heart?

UPPER............   LOWER................

6. What do you think is the function of the valves?

7. How does the heart deal with the two types of blood (oxygenated & deoxygenated)?

8. The blood flows around your body, heart and lungs in a continuous circular pattern. Show that you understand the order of blood flow by filling the empty brackets using numbers 1 to 8, starting with....... (1) *from body;*

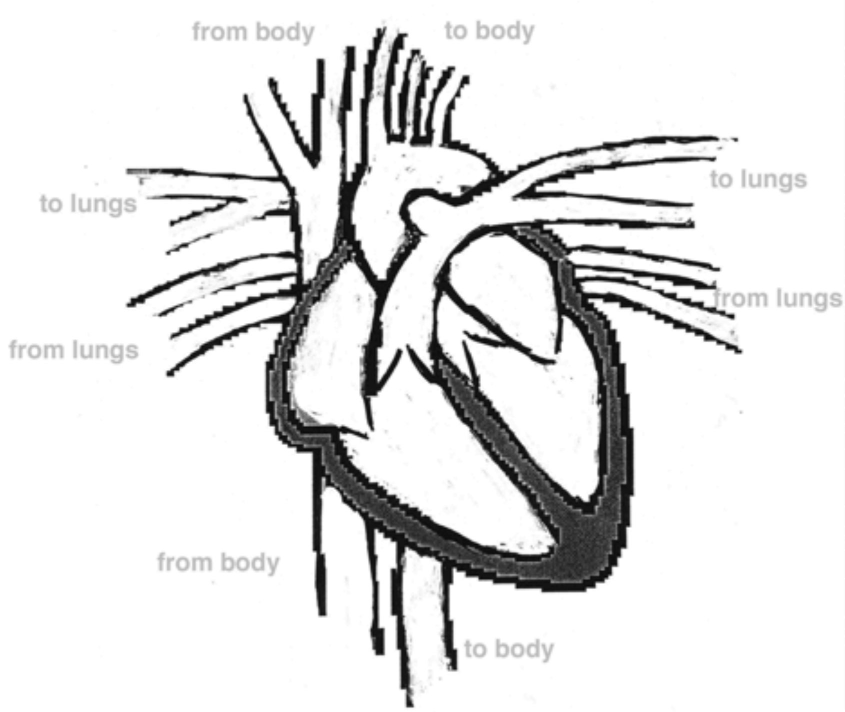
(   ) to body   (   ) to right ventricle

(1) *from body*   (   ) to left ventricle

(   ) to lungs   (   ) to right atrium

(   ) from lungs   (   ) to left atrium

(ii) diagram



a. Examples of open ended questions used

1. What do you think is the main function of the heart?

2. Can you tell me anything about how the heart is divided?

3. Can you tell me anything about the valves?

3. Can you tell me anything about HOW the heart works?

4. Can you tell me anything about the blood that the heart has to deal with?

5. Can you show me the pathway that the blood takes through the heart, where does it come from and where does it go to?

Appendix 8

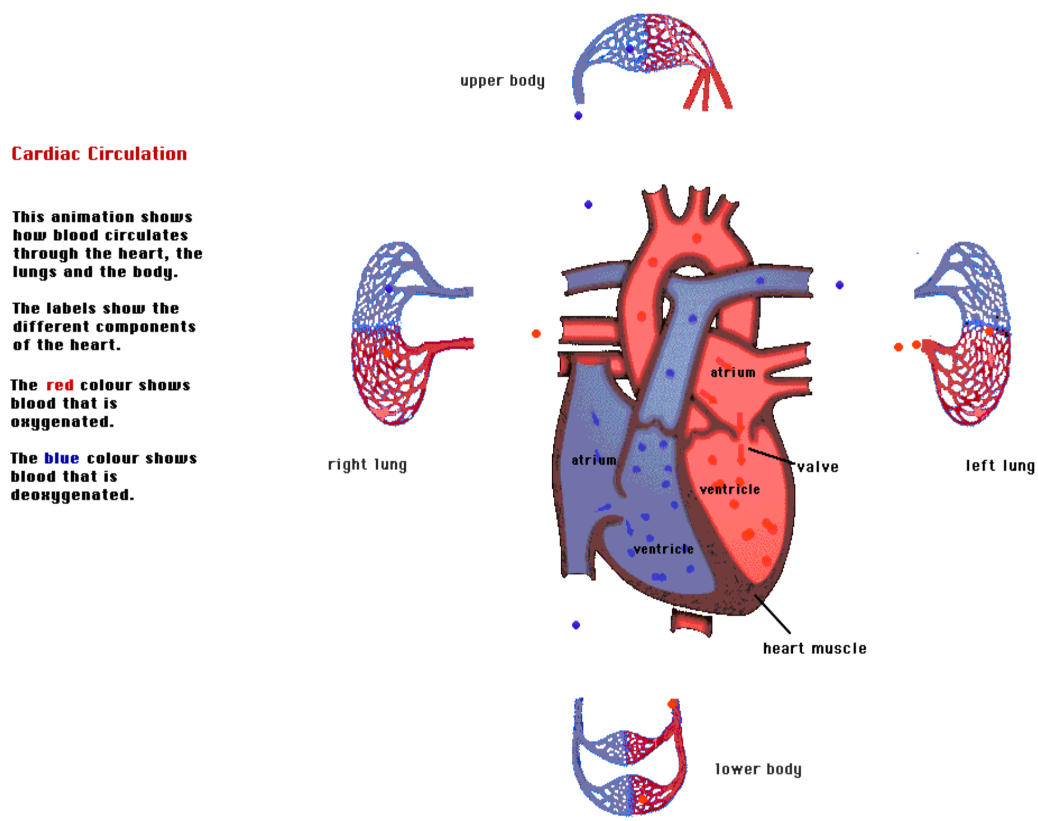
Animations

(Study 3 and study 4)

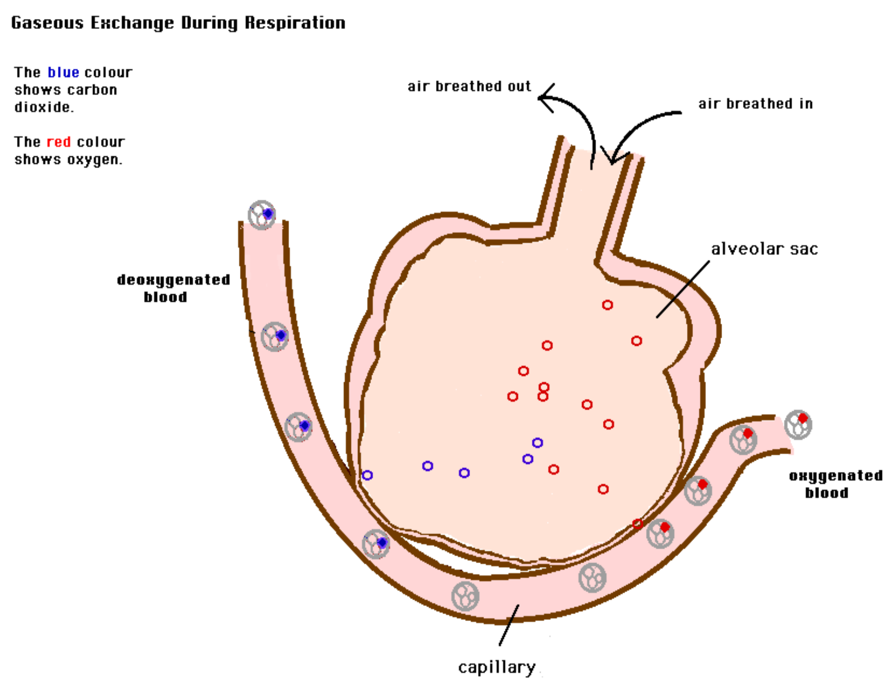
see CD ROM "Animations studies 3 and 4"
"Heart one run" and "Respiration one run"

Example frames:

(i) heart animation



(ii) respiration animation



Appendix 9a

Written tests

Study 3

(i) Heart Questionnaire

1. The following statements refer to movements or changes that happened in the animation?

Tick as many of the following statements that you think are true of the red dots?

- they change into blue dots
- they enter the heart from the body
- they leave the heart and go to the upper body
- they enter the heart from the lungs
- they mix with the blue dots in the heart
- when they leave the heart they go to the lungs

Tick as many of the following statements that you think are true of the blue dots?

1. They changed into red dots in the body
2. They changed into red dots in the lungs
3. They enter the heart from the lungs
4. They enter the heart from the body
5. They go from the heart to the lungs
6. They change into blue arrows

Did the ventricles change? If so, in what way?

Did the valves in the heart change? If so in what way?

Did the heart muscle change? If so in what way?

Did the blood always flow at the same speed?

2. Where does the oxygenated (red) blood come from before it enters the heart?

3. Where does the deoxygenated (blue) blood come from before it enters the heart?

4. Where does the oxygenated (red) blood go to when it leaves the heart?

5. Where does the deoxygenated (blue) blood go to when it leaves the heart

6. In the animation what is the meaning of the following events/ changes:

- The red dots turn into red arrows

- The blue dots change to red dots

- The red dots change to blue dots

- The ventricles get larger and smaller

- The heart muscle gets thinner and thicker

- The heart valves separate and join together

- The blue and red arrows alter speed

7. What is the main function of the heart?

(ii) Respiration Questionnaire

1. Put a circle around the statement you think is true?

Which statement is true about the blue circle in the animation
- it stays inside the grey circle throughout the animation
- it changes to a red circle
- it disappears within the alveolar sac
- it appears in the alveolar sac

Which statement is true about the red circle in the animation
a) it changes to a grey circle
b) it appears in the alveolar sac
c) it disappears in the alveolar sac
d) it changes to a blue circle

Which statement is true of the grey circle in the animation
a) It does not change throughout the animation
b) It loses a red circle and gains a blue circle
c) It loses a blue circle and gains a red circle
d) It disappears in the alveolar sac

Which of the following statements are true?
- The blue circle moves from the capillary to the alveolar sac
- There are more blue than red circles in the alveolar sac
- The thickness of the wall of the alveolar sac is the same all around it
- The red circle moves from the capillary to the alveolar sac
- The thickness of the wall of the alveolar sac differs in some places
- There are more red than blue circles in the alveolar sac.

2. What kind of blood enters the capillary?

3. Why does this blood pass by the alveolar sac?

4. Where does the blood then go to when it leaves the capillary?

5. In the animation what do the following events/ changes show: (what do they mean)?

- The grey circle moving along a pathway

- The blue circle leaving the grey circle

- The blue circles disappearing in the alveolar sac

- The red circles appearing in the alveolar sac

- The red circle entering the grey circle

- A larger number of red circles than blue circles in the alveolar sac

6. Why are the following important for gas exchange in the lungs?

- There is more oxygen than carbon dioxide in the alveolar sac

- The wall (membrane) between the alveolar sac and the capillary is thinner than the rest of its walls.

7. What is the main purpose of respiration.

Appendix 9b

Categorisation of test questions

(Study 3)

Heart animation

Salience category consisted of all of question 1	(total possible score = 19)
Interpretation category consisted of all of question 6	(total possible score = 7)
Conceptual category consisted of questions 2 to 5 and 7	(total possible score = 6)

Respiration animation

Salience category consisted of all of question 1	(total possible score = 9)
Interpretation category consisted of question 5	(total possible score = 6)
Conceptual category consisted of 2,3,6 and 7	(total possible score = 7)

Question 4 was removed from the analysis as it turned out to be ambiguous.

Appendix 10

Tests (Study 4)

(i) Questionnaire heart animation

The following statements refer to movements or changes in blood flow. Tick to indicate whether each statement is true or false or tick 'unsure' if you really don't know.

1. Which of the following statements **about the red dots** are true or false	**true**	**false**	**unsure**
A they change into blue dots			
B they enter the heart from the body			
C they leave the heart and go to the upper body			
D they enter the heart from the lungs			
E they mix with the blue dots in the heart			
F when they leave the heart they go to the lungs			

Which of the following statements **about the blue dots** are true or false	**true**	**false**	**unsure**
G They changed into red dots in the body			
H They changed into red dots in the lungs			
I They enter the heart from the lungs			
J They enter the heart from the body			
K They go from the heart to the lungs			
L They change into blue arrows			

2. Which of the following statements about the animation are true or false	**true**	**false**	**unsure**
A The ventricles do not change throughout the animation			
B The ventricles get bigger and smaller at the same time			
C The ventricles get bigger and smaller at alternate times			
D the ventricle gets bigger when the atrium got smaller			
E the heart muscle surrounds only the ventricle			
F the heart muscle contracts around the atrium			
G the heart muscle gets thinner and thicker			
H there are 4 valves in the heart			
I the valves do not move			
J there are 2 valves in the heart			
K the valves open and close at different times			
L the valves all open and close at the same time			
M when the dots leave the heart they go faster			

3. a) Where does the oxygenated (red) blood come from before it enters the heart?

2. Where does the deoxygenated (blue) blood come from before it enters the heart?

3. Where does the oxygenated (red) blood go to when it leaves the heart?

4. Where does the deoxygenated (blue) blood go to when it leaves the heart

4. In the animation what is the meaning of the following events/ changes:

- The red dots turn into red arrows

- The blue dots change to red dots

- The red dots change to blue dots

5. Tick which of the following statements are true or false.

The ventricles get bigger and smaller because…	**true**	**false**	**unsure**
They allow air in and out			
They fill with blood			
They empty of blood			
They do not change throughout the animation			
The heart muscle gets thinner and thicker because….			
It is contracting to pump blood			
it is contracting to breathe out			
it is expanding as blood flows in			
it is expanding to breathe in			
The heart valves separate and join together..			
To pump blood through the heart			
To let blood flow through			
To stop backflow of blood			
They do not open and close			

6. What is the main function of the heart?

(ii) Test respiration animation

(Study 4)

Questionnaire respiration

1. Put a circle around the statement you think is true?

Which one statement is true about the blue circle in the animation

- it stays inside the grey circle throughout the animation
- it changes to a red circle
- it disappears within the alveolar sac
- it appears in the alveolar sac

Which one statement is true about the red circle in the animation

e) it changes to a grey circle
f) it appears in the alveolar sac
g) it disappears in the alveolar sac
h) it changes to a blue circle

Which one statement is true of the grey circle in the animation

e) It does not change throughout the animation
f) It loses a red circle and gains a blue circle
g) It loses a blue circle and gains a red circle
h) It disappears in the alveolar sac

2. Indicate which of the following statements are true or false or tick 'unsure' if you don't know

	true	false	unsure
The blue circle moves from the capillary to the alveolar sac			
There are more blue than red circles in the alveolar sac			
The thickness of the wall of the alveolar sac is the same all around it.			
The red circle moves from the capillary to the alveolar sac			
The thickness of the wall of the alveolar sac differs in some places.			
There are more red than blue circles in the alveolar sac			

3. a) What kind of blood is flowing into the capillary?

b) Why does this blood pass by the alveolar sac?

4. In the animation what do the following events/ changes show?

- The grey circle moving along a pathway
- The blue circle leaving the grey circle
- The blue circles disappearing in the alveolar sac
- The red circles appearing in the alveolar sac
- The red circle entering the grey circle
- A larger number of red circles than blue circles in the alveolar sac

5. Which of the following help diffusion (the process by which gases are exchanged in the lungs) to take place.

	true	**false**	**unsure**
A higher concentration of oxygen than carbon dioxide in the alveolar sac			
A higher concentration of carbon dioxide than oxygen in alveolar sac			
A thinner wall (membrane) between the alveolar sac and the capillary			
The carbon dioxide changes into oxygen in the alveolar sac			

6.What is the main role of respiration?

Appendix 10b

Categorisation of questions

(Study 4)

Heart animation

Salience category consisted of questions 1 and 2	(total possible score = 25)
Interpretation category consisted of questions 3 and 4	(total possible score = 7)
Conceptual category consisted of questions 5 and 6	(total possible score = 14)

Respiration animation

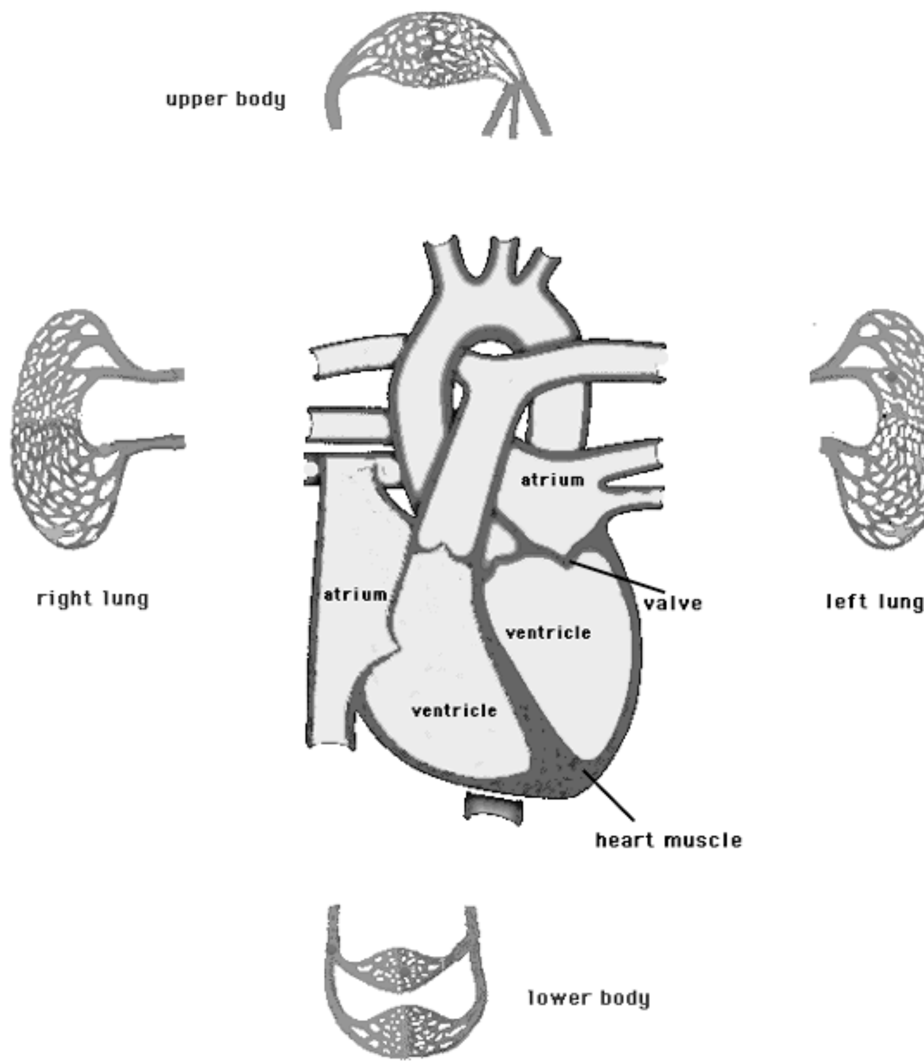
Salience category consisted of questions 1 and 2	(total possible score = 9)
Interpretation category consisted of question 4	(total possible score = 6)
Conceptual category consisted of questions 3, 5 and 6	(total possible score = 9)

Appendix 11

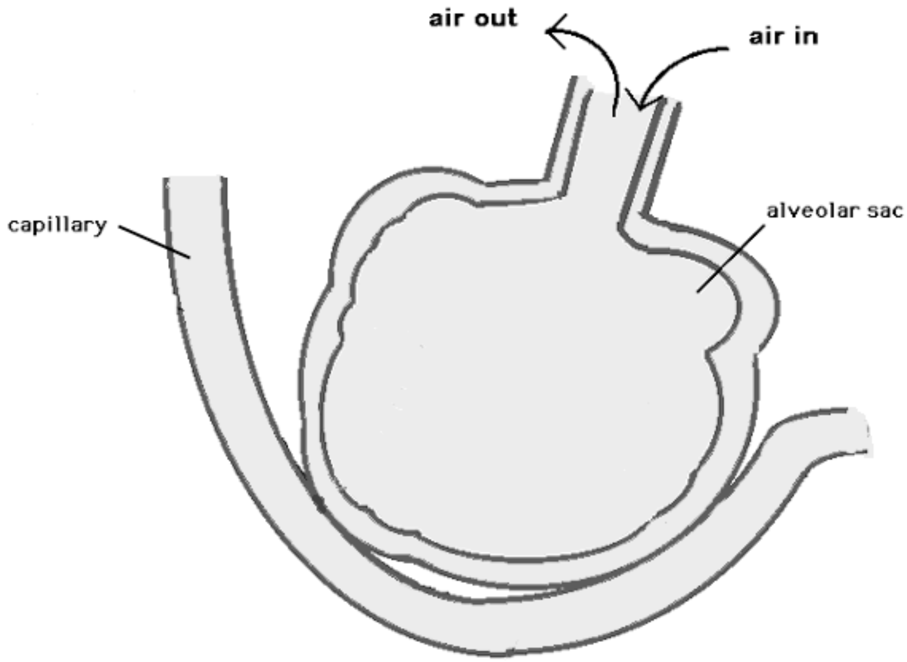
Diagrams to accompany test questions

(Study 3 and 4)

(i) Diagram heart (black and white) accompanying questionnaire



(ii) Diagram respiration (black and white) accompanying questionnaire



Appendix 12a

Pre tests A and B

(Studies 5 and 6)

(i) Question set A – pre-test

NAME …………………………………………………   CLASS…………………

Please answer all of the following questions in the spaces below each question. Try to give short answers only.

1. What kinds of blood flow through the heart?

2. Where does the blood come from before it enters the lungs?

3. Where does blood go to after it leaves the lungs?

4. How does the blood get to the lungs?

5. Oxygenated blood flows out of the heart – where does this blood go to?

6. Why is blood pumped around the body?

(ii) Question set B (pre-test)

NAME……………………………………………… CLASS …………………..

Please answer all of the following questions in the spaces below each question. Try to give short answers only.

1. Why is the heart separated into two main compartments?

2. Where does the blood come from before it enters the body?

3. Where does blood flow to after going round the body?

4. How does the blood get to the body?

5. Deoxygenated blood flows out of the heart – where does this blood go to?

6. Why is blood pumped to the lungs?

Appendix 12b

Post tests A and B

(Studies 5 and 6)

(i) Question set A

NAME ………………………………………………… CLASS…………………

The following Questions ALL refer to the heart and circulatory system. Please answer all questions in the spaces below each question. Try to give short answers only.

1. What kinds of blood flow through the heart?

2. Where does the blood come from before it enters the lungs?

3. Where does blood go to after it leaves the lungs?

4. How does the blood get to the lungs?

5. Oxygenated blood flows out of the heart – where does this blood go to?

6. Why is blood pumped around the body?

7. Tick which of the following are true. The main functions of the heart are ………

a) To pump oxygenated blood to the body
b) To pump deoxygenated blood to the body
c) To pump oxygenated blood to the lungs
d) To pump deoxygenated blood to the lungs
e) To oxygenate the blood
f) To remove carbon dioxide from the blood

8. What changes occur to the blood during the blood flow cycle? Where does each change take place? Why?

change	**where**	**why**

(ii) Question set B

NAME……………………………………………… CLASS …………………..

The following Questions ALL refer to the heart and circulatory system. Please answer all of the following questions in the spaces below each question. Try to give short answers only.

1. Why is the heart separated into two main compartments?

2. Where does the blood come from before it flows around the body?

3. Where does blood flow to after going round the body?

4. How does the blood get to the body?

5. Deoxygenated blood flows out of the heart – where does this blood go to?

6. Why is blood pumped to the lungs?

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7. Tick which of the following are true. The main functions of the heart are ………

a) To pump oxygenated blood to the body
b) To pump deoxygenated blood to the body
c) To pump oxygenated blood to the lungs
d) To pump deoxygenated blood to the lungs
e) To oxygenate the blood
f) To remove carbon dioxide from the blood

8. What changes occur to the blood during the blood flow cycle? Where does each change take place? Why?

change	**where**	**why**

Appendix 13

Diagram test **(screen dump)**

(Study 6)