Navigation and Learning in Electronic Texts

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October 2004

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Acknowledgements

Steph and Helen are great. So is my mum and so is Alex ☺. Thanks also go to my experimental participants and everyone at the Centre for HCI Design. Finally, thanks to Romain Zeiliger for his help with Nestor Navigator.

Declaration

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Abstract

Electronic texts are an essential component of many e-Learning environments and previous research has shown that the type of navigation aid employed has a significant impact upon the quality of learning with such texts. This thesis provides a rich insight into the types of navigation aids that are most effective in educational electronic texts and extends previous research in this area by means of theoretical and empirical investigations.

A comprehensive framework of constructivism and navigation is presented that describes key themes in constructivism and implications of these themes for navigation aids in educational electronic texts. This framework is used to formulate hypotheses about navigation aids and learning, and a subset of these hypotheses is then selected for further investigation. The selected hypotheses build on previous empirical research on navigation and learning and concern the effects of navigational freedom (the degree of choice a learner has in deciding which page to visit in an electronic text) and the effects of a novel approach to navigation: allowing learners to create their own navigation aids. Two experimental studies test these hypotheses and a third then extends the research.

Experiment 1 investigates the effects on learning of the level of navigational freedom offered by a navigation aid. Experiment 2 investigates the effects on learning of allowing the learner to create their own navigation aids. The findings from these experiments indicate that navigational freedom and allowing learners to create their own navigation aids have little or negative impact on learning. Experiment 3 extends the work in experiment 2 by examining the effects on learning of allowing learners to adapt existing navigation aids, and focuses in particular on adapting maps. The findings indicate that allowing learners to adapt maps has benefits for some aspects of learning, cognitive load and usability.

There are four main contributions of the thesis that may be used to inform future research on navigation and learning. Firstly, the framework of constructivism provides a broad context for investigations into the effects of navigation aids on learning. Secondly, three in depth experimental studies are presented. Thirdly, detailed analyses of the experimental data are conducted. Finally, the results of these analyses are distilled into a set of practical implications that can be used to inform designers and researchers of educational electronic texts.

1 Introduction

This chapter introduces the research problem and presents an outline of the thesis.

1.1 Background and Motivation

Navigation in information spaces has received considerable attention within the Human-Computer Interaction (HCI) community and is often reported as problematic. For example, in 1987 Conklin first described the problem of users getting lost in hyperspace (Conklin, 1987). Ten years later, at the CHI '97 workshop entitled "Navigation in Electronic Worlds", there was still considerable debate over definitions of navigation and how to design effective navigation (Jul and Furnas, 1997). Following on from this, Spence (2002) developed a framework of navigation activity, and described navigation in information space as an "interactively controlled – and usually iterative – movement", or "translation". Benyon and Wilmes (2003) also investigated navigation and considered the extent to which design principles from the built environment transferred to information spaces. Navigation has also received attention in the field of e-Learning. For example, Boechler and Dawson (2002) have studied navigation behaviour, and McDonald and Stevenson (1999) have investigated the effects of different approaches to navigation on learners' understanding of the content of an electronic text.

The rapid expansion of the World Wide Web (WWW) has led to a surge in e-Learning in higher education. In the USA, the University of Phoenix Online offers degree programmes via the internet to 100,000 students worldwide in ninety-four countries, and expects to see a 60% growth in 2004 (Anderson, 2004). Similarly, in the UK, The Open University has invested £30 million in e-Learning in recent years and approximately 160,000 of their students and tutors are online (The Open University, 2004). Given the scale of the audience and investment in this area, it is crucial that e-Learning environments support effective learning.

One approach to designing effective e-Learning is to build constructivist learning environments (Jonassen, 1999). Constructivism has had "major ramifications" for instructional strategies and assessment in modern education (Fosnot, 1996) and the central claim of the constructivist approach is that knowledge and meaning are not fixed, but rather are constructed through experience (Honebein et al., 1993). In this context learning is understood as the *process* of knowledge development including the learner's feelings about this process.

Electronic texts are an essential component of many e-Learning environments, and previous research has shown that the navigation can affect the learners' understanding of the content of an educational electronic text (Dee-Lucas and Larkin, 1995; McDonald and Stevenson, 1999; Stanton et al. 1992). The way that the user interface is designed to support navigation activity in educational electronic texts is critical since it determines how effectively learners can traverse the educational content. This thesis takes a novel approach to investigating navigation and learning in electronic texts within the broad context of constructivism. In particular, the research focuses on the effects of *navigation aids* on learning.

1.2 Definitions: Electronic Texts and Navigation Aids

In this research, "electronic text" is used as a generic term to refer to text presented in an electronic medium. Examples include hypertext documents (nodes of text connected by embedded links), text organised in menu structures, or linear text organised as a set of sequential nodes. This text may be presented in a variety of ways including via the WWW and stand-alone CD-ROMs. "Navigation aids" are defined here as elements of an interface that aid the access and traversal of electronic texts and examples include embedded links, menus, interactive maps, and bookmarks.

1.3 Previous Research on Navigation Aids

From an HCI perspective, a number of studies have examined the effects of different types of navigation aids on *navigation performance*, with mixed findings. For example, Gupta and Gramopadhye (1995) found that navigation performance with maps, A-Z indices and plain hypertext (embedded links) is dependent on the size of the electronic text. They also found that maps are the most effective navigation aid in terms of reducing the total time it takes to find information, as compared to A-Z indices and plain hypertext. More recently, Nilsson and Mayer (2002) assessed the effects of a "graphical organiser map" on website navigation performance compared to navigation performance in the same website with no map. They found the map led to more efficient navigation while users gained familiarity with a website (the users visited fewer pages). However, when the users were more experienced with the website, those who used the website without a map were more efficient. Another study by Danielson (2002), examined the effects on navigation performance of constantly visible textual contents lists that showed a hierarchical organisation of a website, compared to a control group given a website with no contents list. Danielson found that users of the contents list abandoned fewer information-seeking tasks, dug deeper into the site hierarchy, spent more time at lower levels, and made less use of the back button than users in the control group.

The above studies considered the effects of navigation aids on navigation performance. However, in e-Learning environments it is the effects of navigation aids on *learning* that are crucial. Research that has investigated these effects has also revealed mixed results. For example, Dee-Lucas and Larkin (1995), McDonald and Stevenson (1997b), and McDonald and Stevenson (1999) all report studies where it was found that navigation aids that show overviews of the electronic text, such as maps, contents lists, and A-Z indices, have benefits for learning with electronic texts compared to systems of plain hypertext where embedded links are the only available navigation aids. However, in contrast, Wenger and Payne (1994) and Stanton et al. (1992) found that providing maps as navigation aids had little or negative effects on learning with electronic texts as compared to plain hypertext. This research is discussed further in chapter 2. The mixed results indicate that the effects of navigation aids in educational electronic texts are complex and further investigation is needed.

This thesis extends previous research by examining how navigation aids impact learning from the perspective of constructivism. Here learning is understood as the process of knowledge development and in this thesis learning is examined in terms of cognitive engagement, the learners' feelings of ownership for their learning, and the quality of the resulting knowledge construction. In particular, theoretical and empirical investigations explore the effects of navigation aids on learning with electronic texts.

A detailed framework of constructivism and navigation is presented. This provides a broad context for implications and hypotheses about navigation aids and learning. Three in-depth experimental investigations are then reported which test a set of hypotheses motivated by the framework. Experiment 1 investigates the effects on learning of navigational freedom (the degree of choice a learner has in deciding which page to visit in an electronic text) offered by a navigation aid. Experiment 2 investigates the effects on learning of allowing the learner to create their own navigation aids. Experiment 3 extends the work of experiment 2 and examines the effects on learning of allowing learners to adapt existing navigation aids; this experiment focuses in particular on navigation maps.

1.4 Research Aim and Objectives

The overall aim of this research is to provide a rich insight into the effects of navigation aids on learning with educational electronic texts within the wider context of constructivism.

Further to this, there are four main objectives of the research:

1. To define a detailed framework of the essential features of constructivism and its implications for navigation aids in educational electronic texts.
2. To use this framework to formulate hypotheses about the effects of different types of navigation aids on learning with electronic texts.
3. To empirically test hypotheses that were motivated by the framework of constructivism and navigation.
4. To distil the findings of the empirical investigations into a set of implications to inform designers and researchers of educational electronic texts.

1.5 Thesis Scope

The problem of how navigation aids affect learning in educational electronic texts is addressed in this thesis and there are several issues that are important to understanding this problem and its scope. Firstly, in terms of the underlying epistemology, theories of knowledge and learning can be broadly described as related to objectivist or constructivist epistemologies; in this thesis, learning is described from a constructivist perspective. Secondly, in terms of research in HCI, this thesis focuses on navigation aids. Other interface elements, such as multimedia, visual layout, and communication, may also have an impact on the quality of learning with technology, but these are outside the scope of the thesis. The third aspect of the thesis scope is the type of e-Learning technology. In this thesis, the focus is on educational electronic texts. Other aspects of e-Learning environments, such as simulations or discussion boards have their own particular concerns, and again are beyond the scope of this work. The thesis scope is summarised in figure 1.1.

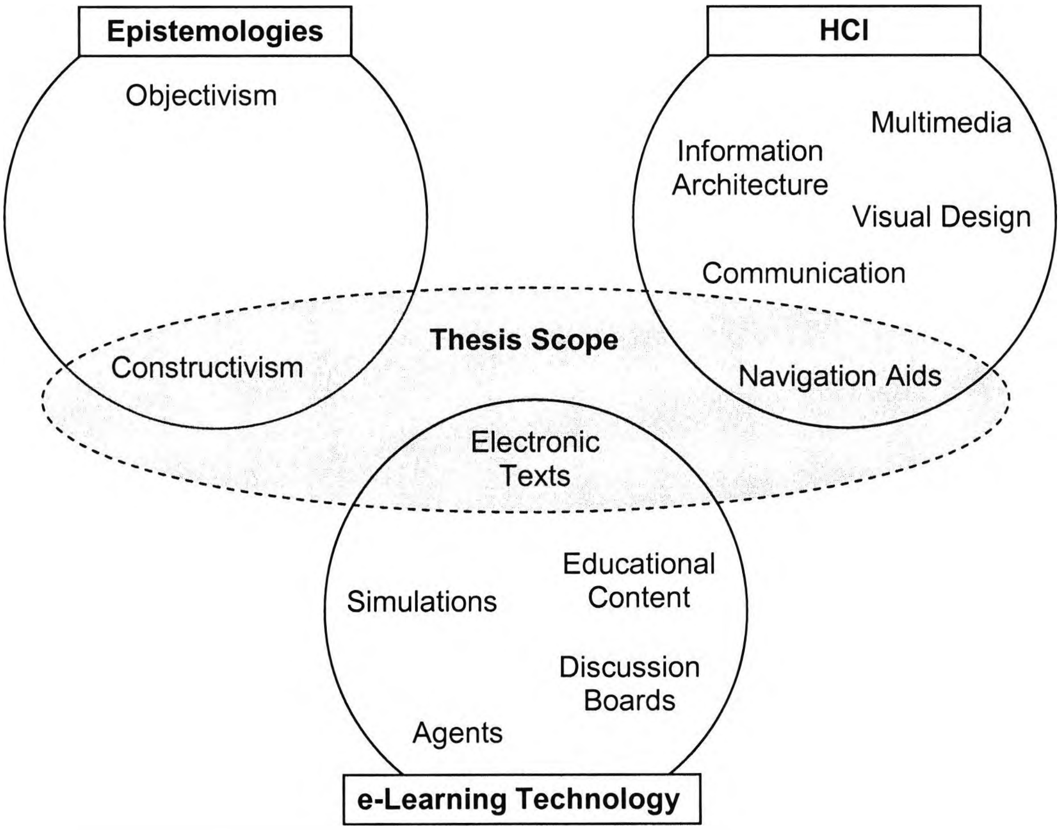

Figure 1.1. Scope of the thesis. Note that in each of these areas the examples given are not exhaustive.

1.6 Research Methods

To achieve objective 1, a framework of constructivism is developed. An extensive review of literature on constructivist principles and constructivist approaches to education contributes to this framework. The framework organises the literature as a set of constructivist themes, and each theme is examined in terms of its relevance and implications for navigation aids in educational electronic texts.

To achieve objective 2, the implications for navigation aids from the framework of constructivism are developed into a set of hypotheses concerning the effects of navigation aids on learning. A sub-set of these hypotheses is then selected for further investigation. These hypotheses build on previous research on navigation and learning.

To achieve objective 3, three thorough experimental investigations into the effects of navigation aids on learning with electronic texts are described and detailed data is presented from studies involving over one hundred learners. In line with a constructivist approach, learning is tested from the perspectives of cognitive engagement, feelings of ownership for learning, and knowledge construction in these experiments. In addition, post-hoc assessments of navigation behaviour and usability are examined in the experiments for potential explanations of findings on the learning measures. In experiment 3 the level of cognitive load associated with using the electronic texts is also addressed.

Finally, for objective 4, the results of the three experimental studies are analysed and the findings of each are compiled into a set of implications for navigation aids in educational electronic texts.

1.7 Organisation of the Thesis

This thesis consists of seven chapters. The next chapter, chapter 2, presents a review of relevant background literature. It includes an introduction to constructivism and its place in relation to objectivist theories of learning, different versions of constructivism, and proposed principles of constructivism. e-Learning technologies and their history are then examined. This is followed by a discussion of the nature of navigation in information spaces and, in particular, issues related to navigation in electronic texts. The chapter then presents examples of navigation technologies developed to support navigation in educational environments, and previous experimental research on navigation aids and learning.

Chapters 3 to 7 describe the research conducted to meet the thesis objectives. Chapter 3 presents a framework of constructivism and navigation that includes implications and hypotheses about the effect of navigation aids in educational electronic texts on learning. A sub-set of hypotheses is selected to be empirically tested.

Experiment 1 is presented in chapter 4. This experiment concerns the effects on learning of the level of navigational freedom offered by four different navigation aids: paging buttons (lower navigational freedom); embedded links (medium navigational freedom); an A-Z index (higher navigational freedom); and a map (higher navigational freedom). The method, analysis, and results of this study are described and the implications are discussed.

Chapter 5 describes experiment 2 which investigates the effects on learning of a novel approach to navigation: allowing the learner to create their own navigation aids. The study has three parts. Part A examines the effects of using vs. creating navigation maps on learning. Part B examines the effects of using vs. creating A-Z indices on learning. Finally part C examines the effects of using vs. creating contents lists on learning. Again, the method, analysis and results are described and the implications are discussed. It should also be noted that since parts of experiment 2 were conducted at the same time as experiment 1, some of the data analysis and checking for reliability and validity of the measures was conducted together (details of this are discussed in chapters 4 and 5).

In chapter 6 the method, analysis and results of experiment 3 are presented. The experiment extends the work in experiment 2 and concerns the effects on learning and cognitive load of allowing learners to adapt existing navigation aids, and focuses in particular on map navigation aids. The analysis and results are described and the implications of the findings are discussed.

Finally, chapter 7 discusses the overall implications of the thesis research, its limitations, and possible future research directions. The structure of the thesis is summarised in figure 1.2.

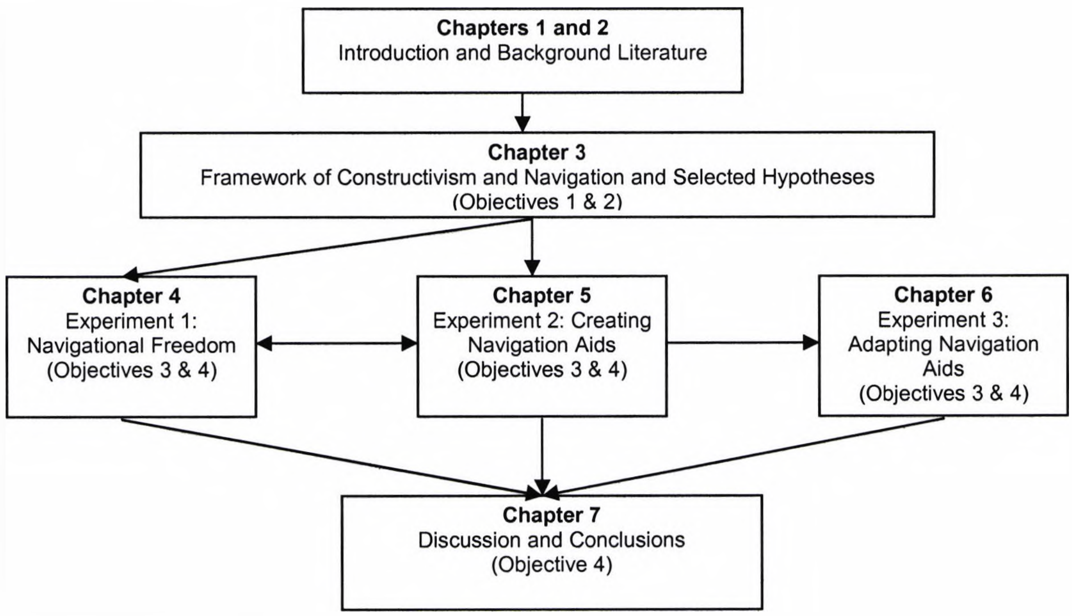

Figure 1.2. The structure of the thesis and relation to the thesis objectives. Arrows depict the relationships between the content of each of the chapters.

1.8 Contributions of the Research

This thesis makes contributions to research on navigation and educational electronic texts. To summarise, the four main contributions are:

- ⇨ A framework of constructivism and navigation. This is a novel approach to examining the effects of navigation aids on learning with electronic texts. The framework consolidates previous constructivist literature into one version of constructivism for use in this thesis and identifies key themes in constructivism. The framework highlights implications and hypotheses for navigation aids in educational electronic texts and provides a broad context for investigations into the effects of navigation aids on learning.

⇨ Three in-depth experimental studies into the effects of navigation aids on learning with electronic texts. These represent controlled experiments that investigate the effects of navigation on learning from a constructivist perspective.

⇨ Substantial qualitative and quantitative analyses of the experimental data are conducted. These analyses provide detailed insight into the effects of navigation aids including the effects on learning, cognitive load, usability, and navigation behaviour.

⇨ Experimental findings are interpreted and distilled into implications that can be used to inform designers and researchers of educational electronic texts. These implications provide information about the key findings of the experiments and what they mean for designers and researchers.

Two secondary contributions are:

⇨ Novel approaches to assessing learning with electronic texts are developed and employed in the experiments. These include assessing the learning process as a whole in terms of cognitive engagement, feelings of ownership for learning, and knowledge construction.

⇨ Detailed (post-hoc) analyses of usability, cognitive load and navigation behaviour are conducted. These represent methodological contributions in terms of techniques to assess usability, cognitive load and navigation behaviour in electronic texts.

2 Navigation, Learning and Technology

This chapter introduces theory and presents background literature for the thesis.

2.1 Introduction

This thesis investigates the effects of navigation aids on learning with educational electronic texts. As discussed in chapter 1, previous research on navigation aids has demonstrated that this is a complex problem and there are several issues which are important to understanding this problem and its scope.

Firstly, human knowledge and learning need to be understood. In this thesis, learning is described from a constructivist perspective and this chapter begins by introducing the basic tenets of a constructivist epistemology and constructivist explanations of learning (see section 2.2).

Secondly, the type of e-Learning technology is important to defining the scope of the thesis, and this research focuses on learning with electronic texts. To provide a background for this, a review of educational technologies and their history is presented here (see section 2.3).

Thirdly, since there has been debate over the meaning of navigation in electronic environments, it is important that related issues are given precise definitions. This chapter presents a review of these issues. Note that this review is not just confined to navigation in educational environments, but considers navigation in electronic environments in general (see section 2.4).

Finally, a review of recent developments in navigation technology is presented, followed by a review of experimental research into the effects of navigation aids on learning (see section 2.5). This highlights areas for further investigation in this thesis.

2.2 Theories of Knowledge and Learning

The main tenets of two theories of knowledge, objectivism and constructivism, are reviewed here. This sets a background for the framework of constructivism and navigation presented in chapter 3.

2.2.1 Constructivism or Objectivism?

Both objectivism and constructivism are epistemologies or theories of knowledge. They represent opposite ends of a continuum, with constructivism at one end and objectivism at the other (Vrasidas, 2000; Jonassen, 1991) (see figure 2.1).

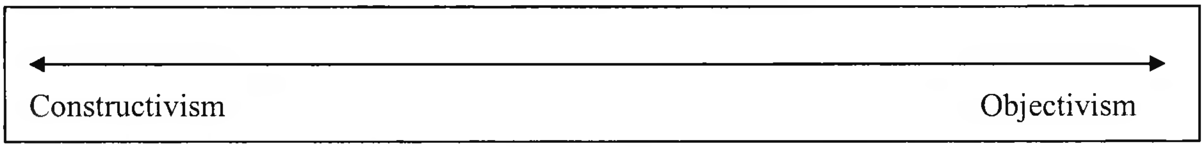

Figure 2.1. The constructivism-objectivism continuum. From Vrasidas (2000).

Objectivists promote the view that there is an objective reality that exists independently of humans (Vrasidas, 2000), and that we all perceive this reality accurately and in the same way. Objectivist conceptions of instructional design involve the analysis, representation and sequencing of content and tasks so that the transmission of knowledge can take place reliably (Jonassen, 1999). Objectivism is related to behaviourist theories of learning, such as Skinner's theory of operant conditioning (e.g. Skinner, 1954). According to Skinner's theory, learning is a change in overt behaviour and occurs through reinforced stimulus-response patterns.

In contrast, the core of the constructivist approach is that knowledge or meaning is not fixed, but rather is constructed through experience (Jonassen, 1994). Since knowledge cannot be transmitted, constructivists argue that instruction should consist of experiences that facilitate knowledge construction (Jonassen, 1999). Constructivist theories of learning include the work of Jerome Bruner, Jean Piaget and Lev Vygotsky. Bruner's theory describes learning as an active process of discovery and learners construct knowledge based on their past experiences (e.g. Bruner, 1960). The work of Jean Piaget focuses on child development (e.g. Piaget, 1970; Piaget and Inhelder, 1973). The social development theories of Lev Vygotsky, on the other hand, describe the process of cognitive development in relation to social interaction (e.g. Vygotsky, 1978).

Constructivism can be viewed at different levels, at a philosophical level, as an epistemology, or as a theory of learning and education. At a philosophical level, as an epistemology, constructivism describes the genesis and nature of knowledge. In contrast, at the level of a theory of learning and education, constructivism describes the factors that affect human learning and the way that education should be conducted to encourage learning. However, the extent to which constructivism forms a complete theory of learning and education has been questioned since it does not always give clear suggestions about how education should be conducted (Murphy, 1997). Accordingly, in the following discussions constructivism will be taken as an epistemology that has implications for learning and education. As stated in chapter 1, learning should be understood here as the *process* of constructing or developing knowledge.

Because of the common conception that constructivism focuses on individuals constructing a unique reality that is only in the mind of the knower, constructivism has been subject to the criticism of "intellectual anarchy". For example, this implies that every individual constructs reality in a completely idiosyncratic manner and this can be used to justify differences between individuals' understandings of a given situation. This suggests that there is no point in evaluating the quality of learning since every learner's knowledge is necessarily different. Misunderstandings can never occur because there is no set reality and no baseline to which the quality of the knowledge can be compared. However, a response to this criticism is to take a Gibsonian perspective that there is a physical world that is subject to physical laws, and we all perceive it in pretty much the same way because of these laws (Jonassen, 1994). From this perspective, when assessing learning there is not always a definite right or wrong in any situation. However, if there is a consensus on the way a particular issue should be understood, then that way of understanding the issue may be more appropriate than others. In this research, favour is given to a constructivist epistemology that takes account of this Gibsonian perspective.

2.2.2 Constructivism or Constructionism?

There are several interrelated concepts that are associated with constructivism, such as radical constructivism, social constructivism, constructionism and social constructionism.

Radical constructivism has roots in rationalist philosophy and emphasises the way that the *individual mind* constructs what it takes to be reality (Gergen, 1999), and the way that knowledge is constructed in social situations is given less attention. Scholars that are often associated with this view include Claude Levi Strauss and Ernst von Glazerfeld.

Social constructivists, on the other hand, argue that the mind constructs reality through its relationship to the world and this process is significantly influenced by *social relationships* (Gergen, 1999). The works of Lev Vygotsky (e.g. Vygotsky, 1978) and Jerome Bruner (e.g. Bruner, 1986) are illustrative of this approach.

Constructionism shares constructivism's connotations of learning as the building of knowledge structures, but also adds the idea that this happens especially "felicitously" when learners are engaged in *constructing public entities* (Papert and Harel, 1991). This public entity is an artefact that can be shared by individuals and may be anything from a sandcastle to a theory of the universe. Constructionism also tends to emphasise social aspects of knowledge construction.

Finally, social constructionism, according to Gergen (1999), places emphasis on *discourse* as the vehicle through which the self and the world are articulated, and the way that this discourse functions within social relationships.

Despite the subtle differences in these definitions, in this thesis constructivism will be viewed as an umbrella concept, as suggested by Squires (1999), that includes elements of all of the above approaches. The details of this version of constructivism can be found in the framework presented in chapter 3.

2.2.3 Principles of Constructivism

There have been several attempts to set out the main tenets of constructivism and their implications for educational practice. Some work has focussed on the distinguishing features of constructivist learning environments (CLEs) (Jonassen, 1999), whereas other work has considered principles of constructivism at a more fundamental level. These fundamental principles of constructivism are shown in table 2.1, presented in order of publication date. These sets of principles form the basis of the framework of constructivism and navigation presented in chapter 3 and are presented here to provide context for the framework.

Authors	Principles of Constructivism
Jonassen et al. (1993)	1. Knowledge construction. 2. Generative processing and active learning. 3. Social negotiation of meaning. 4. Contextually mediated understanding. 5. Reflective thinkers.
Simons (1993)	Six core characteristics of constructive learning: 1. Learning is active. 2. Learning is constructive. 3. Learning is cumulative. 4. Learning is goal oriented. 5. Learning is diagnostic. 6. Learning is reflective. Six secondary characteristics of constructive learning: 1. Learning is discovery oriented. 2. Learning is contextual. 3. Learning is problem oriented. 4. Learning is case-based. 5. Learning is social. 6. Learning is intrinsically motivated.
Knuth & Cunningham (1993)	1. All knowledge is constructed. 2. Many worlds are possible, hence there will be multiple perspectives. 3. Knowledge is effective action. 4. Human learning is embedded within social coupling. 5. Knowing is not sign dependent. 6. World views can be explored and changed with tools. 7. Knowing how we know is the ultimate human accomplishment.
Cunningham et al. (1993)	1. Provide experience of the knowledge construction process. 2. Provide experience in and appreciation for multiple perspectives. 3. Embed learning in realistic and relevant contexts. 4. Encourage ownership and voice in the learning process. 5. Embed learning in social experience. 6. Encourage the use of multiple modes of representation. 7. Encourage self-awareness of the knowledge construction process.
Duffy & Cunningham (1996)	1. All knowledge is constructed; all learning is a process of construction. 2. Many world views can be constructed; hence there will be multiple perspectives. 3. Knowledge is context dependent, so learning should occur in contexts to which it is relevant. 4. Learning should be mediated by tools and signs. 5. Learning is an inherently social-dialogical activity. 6. Learners are distributed, multidimensional participants in a sociocultural process. 7. Knowing how we know is the ultimate human accomplishment.
Fosnot (1996)	1. Learning is not the result of development; learning *is* development. 2. Disequilibrium facilitates learning. 3. Reflective abstraction is the driving force of learning. 4. Dialogue within a community engenders further thinking. 5. Learning proceeds towards the development of structures.
Duffy and Orrill (2003)	1. Learning is situated. 2. Learning is goal driven. 3. Learning is social.

Table 2.1. Principles of constructivism.

Each set of principles has a slightly different emphasis. Jonassen et al.'s (1993) principles present constructivists' assumptions about learning. Those presented by Simons (1993) suggest characteristics of constructive learning. Knuth and Cunningham

(1993) show principles of a constructivist epistemology. In contrast, those given in Cunningham et al. (1993) are presented as pedagogical goals of constructivism and suggest implications for a constructivist approach to education. Again, a different emphasis is given in Duffy and Cunningham (1996), who present the grounding assumptions of their version of constructivism which places emphasis on learning in the context of a constructivist epistemology[1]. Fosnot (1996) offers another perspective, and presents general principles of learning derived from constructivism that can be used to inform educational practice. Finally, more recently, Duffy and Orrill (2003) present key principles of learning from constructivism.

These principles set out the main tenets of constructivism and highlight the fact that there are several perspectives on constructivism. They give a useful basis from which further implications and applications of constructivism can be expanded. To fulfil objective 1 of this research, these constructivist principles are grouped into themes in chapter 3 and are elaborated and extended to account for propositions in other constructivist literature to form the framework of constructivism and navigation.

2.2.4 Section Summary

Learning is defined from a constructivist perspective in this thesis. Constructivism is taken as an epistemology with implications for learning and education, and is used here as an umbrella concept to encompass ideas from related theories such as social constructivism and constructionism. The principles of constructivism suggested in the literature were summarised in this section and this has highlighted the fact that there are many versions of constructivism. As this research takes a constructivist perspective on learning, a single version of constructivism that consolidates previous constructivist literature is needed. To this end, a framework of constructivism and navigation is detailed in chapter 3 and the work presented here in section 2.2 is used as a basis for this framework.

2.3 e-Learning Technologies

The term "e-Learning technology" is used in this thesis to refer to any interactive technology that is intended to educate. As discussed in chapter 1, this thesis focuses on

[1] It should be noted that for the three sets of principles by Cunningham, Duffy and Knuth, it is not clear whether these were developed over time, or whether they were intended to represent different perspectives.

learning with educational electronic texts. In order to provide a background to this, the place of electronic texts is considered in terms of the history of e-Learning technology, as well as in terms of categories of e-Learning technology. Definitions of technologies related to educational electronic texts – hypertext, hypermedia and electronic texts – are then discussed.

2.3.1 History of e-Learning Technology

To give context to the issues surrounding educational electronic texts, this section summarises the key historical examples of the application of technologies to aid learning. An early endeavour came about in the mid-1950s, when the behaviourist B. F. Skinner proposed mechanical teaching machines that could be used to shape the behaviour of learners (Skinner, 1954). These devices were intended to induce learning through the presentation of stimuli with immediate reinforcements. Skinner (1968) proposed that through a series of training sessions the learner would build up a repertoire of correct answers and solutions to problems. However, this approach has been criticised because it forces students to follow the steps predetermined by the programmer, and does not allow for individual creative work (Hartley, 1974). This approach is an archetype of objectivist epistemologies.

With an increase in the availability of computers, as well as developments in new technologies, computers provided a more promising medium to assist learning. Major milestones in the evolution of graphical user interfaces, such as the world debut of the computer mouse (English et al., 1967), and the first use of graphical windows in the Xerox Alto computer in 1972 (Smith et al., 1982), facilitated this transition. In addition, 1969 saw the construction of ARPANET, the precursor to the Internet, at the United States Defence Advanced Research Project Agency (ARPA). A year later, in 1970, one of the first intelligent tutoring systems, named "Scholar" was then developed as an experimental system by Jaime Carbonell (Carbonell, 1970).

The work of Papert (1980) reflected a change in ideas about the way we learn with technology, and his work had a strong focus on constructivism. Papert took concepts such as active learning from the cognitive development theories of Piaget (e.g. Piaget, 1970). These concepts were used as a basis for creating a learning environment, Logo, to teach children programming and mathematical skills.

The mid to late 1980s saw hypertext systems come on to the market as commercial products (for a review see Nielsen, 1995). These systems were based on ideas from the Memex system (Bush, 1945). They used the term "hypertext" coined by

Ted Nelson in 1965 to describe the cross-referencing of information within the system. From 1985 onwards, the Intermedia system was developed at Brown University over a period of several years (e.g. Yankelovich et al., 1988). This was an early example of an integrated hypertext environment designed for educational use. Many other hypertext learning systems have followed, but although several theories have promoted hypertext as beneficial to learners (e.g. Spiro et al., 1991), there has been much debate over the conditions in which hypertext is most effective (Chen and Rada, 1996; Dillon and Gabbard, 1998). Experiments investigating the conditions for effective learning with hypertext and other forms of electronic texts are discussed further in section 2.5.2.

In 1989 the WWW was developed at CERN, the European high energy physics research centre. It was used to distribute information between research groups that were separated geographically and in 1993 Mosaic was released as the first graphical WWW browser. The rapid expansion of this technology in recent years has led to a significant push for universities to develop online courses (Yeung, 2002). In addition the release of the Java language in 1995 was important for e-Learning technologies since it allows interactive multimedia applications to be integrated into WWW documents (Boyle, 1997). The introduction of VMRL (Virtual Reality Modelling Language), also in 1995, offered even more opportunities for multimedia authoring and distribution.

In the mid 1990s there were also important developments in terms of virtual learning environments (VLEs). VLEs are web based learning environments that provide learning tools designed to support students' learning activities. They commonly consist of educational content materials, such as electronic texts, student tracking and electronic communication facilities (email, discussion boards, chat, web publishing). In 1995 WebCT was founded by Murray Goldberg at the University of British Columbia. This was followed by Blackboard in 1997 founded by graduate students at Cornell University. These coincided with the beginnings of a boom in e-Learning in higher education.

In the new millennium there has also been an increasing interest in m-Learning, or mobile learning, that occurs via wireless devices such as mobile phones, personal digital assistants (PDAs) or laptop computers. For example, the m-Learning project is a three-year EU funded project taking place in the UK, Sweden and Italy, that started in October 2001 (Learning and Skills Development Agency, 2004). The aim of the project is to evaluate how mobile devices can be used to teach basic numeracy and literacy skills.

These historical examples of the use of e-Learning technology highlight the fact that designers and researchers have shown continued interest in the use of technology in education. The next section presents categories of e-Learning technology and shows the place of electronic texts within this.

2.3.2 Categories of e-Learning Technology

Boyle (1997) offers a descriptive framework for the classification of e-Learning technologies. He suggests that e-Learning technologies can be divided into four main categories: information dissemination and retrieval; tools and composition support; simulations and vicarious experience; and structured skill and knowledge acquisition. Brief overviews of each of these categories are described in turn.

The first category in Boyle's (1997) framework is information dissemination and retrieval. The use of technologies in information retrieval is often seen as an extension of the traditional format of the encyclopaedia or book. According to Boyle, this format lends itself to enhancement through multimedia presentation of material and hypermedia cross-referencing. Multimedia encyclopaedias and referencing systems are prototypical examples of this type of e-Learning technology. It is also apparent that this type of e-Learning technology plays a key role in disseminating educational information in many e-Learning environments, for example electronic versions of lecture notes often act as an information resource for higher education courses. As such, electronic texts are related to this category.

The second category, tools for composition and support, refers to a range of software tools that allow learners to analyse and manipulate information and construct their own artefacts. This category is divided into "worldtools" and "mindtools". Tools such as word processors or spreadsheets come under the realm of "worldtools" and can be used to support educational activities. "Mindtools", on the other hand, are a more direct set of educational tools that are developed specifically to enhance problem solving and learning. Examples given by Boyle include: concept-mapping tools to provide support for problem solving; construction tools such as Logo (Papert, 1980); collaborative learning tools to support communication and learning in groups; multimedia composition tools; and domain specific tools such as support for learning program design.

The third category, simulations and vicarious experience, can be broken down into the themes of simulation, games, and virtual reality. Acting in a simulated environment may lead the learner to acquire skills and knowledge, whereas gaming structures based on those in arcade or adventure games are a powerful way to promote engagement. Boyle (1997) suggests that the ultimate expression of simulation is virtual reality, which he claims is one of the most powerful media for educational systems.

The final group of educational technologies given by Boyle (1997) is that relating to structured skill and knowledge acquisition. This category includes intelligent tutoring systems (ITS), guided discovery learning environments, and adaptive hypermedia and intelligent assistants. With regard to ITSs, Boyle suggests that their primary aim is to generate content and teaching actions that are adaptive to the needs of individual learners. ITSs attempt to act as a personal tutor. Alternatively, guided discovery environments attempt to support natural learning strategies. They are built so that the user can adapt the environment to their individual needs. Adaptive hypermedia systems are those where an intelligent component is added to a hypermedia system to provide adaptive guidance for the learner. On the other hand, intelligent assistants provide an embodiment of the adaptive element of the system in the form of an interface avatar. A key feature of these is that they provide assistance rather than direction for the learner.

In summary, Boyle's (1997) framework is useful for the descriptive categorisation of e-Learning technologies. The focus of this thesis is on electronic texts, which fall under the first category of tools for information dissemination and retrieval. The other examples presented offer a background to electronic texts as educational technologies. However, as will be discussed in section 2.5.1, we may see how navigation in electronic texts can be designed such that the texts become more interactive and may relate to mindtool environments. The remainder of this section presents definitions of hypertext, hypermedia and electronic texts.

2.3.3 Definitions of Hypertext, Hypermedia and Electronic Texts

As discussed earlier, electronic texts are an essential component of many e-Learning environments. The related terms "hypertext" and "hypermedia" are sometimes used synonymously with electronic texts. However, in this thesis the subtle differences in these terms are important since they reflect different structures and content. According to Nielsen (1995) hypertext systems are those consisting of textual nodes and embedded links that allow the user to "jump" from one node to another. They encompass the notion of cross-referenced information (Nelson, 1965) and imply a system of pure text. An example of a hypertext system where the nodes are purely textual is Hyperties (Schneiderman, 1987).

The term "hypermedia" is sometimes used synonymously with hypertext. However, a more correct usage of "hypermedia" is to stress the multimedia aspects of a system, and refers to multimedia plus linking (de Vries, 1996). The nodes in a hypermedia system can be of any media type for example text, graphics audio or video. The WWW is an example of a global hypermedia system.

Nielsen (1995) focused on the informational aspects of hypermedia to distinguish it from other applications. He emphasised the importance of interactivity and control in the exploration of the information space, rather than passive involvement. High levels of user control also entail that users may take unexpected routes through the system. This is of particular significance to web design, and differs from traditional graphical user interface (GUI) design in that designers cannot grey out options or links to prevent unsuitable routes being taken (Nielsen, 2000).

Nevertheless, the definitions of hypertext and hypermedia given above do not apply to all types of navigation structures on the web, or in other navigable presentations of information. Information can be organised so access is purely through menus or graphical representations of the information. In these instances the content of each of the nodes may not contain embedded links and the strict definitions of hypertext and hypermedia are not always appropriate to describe such systems. Here more generic definitions are useful to encompass all types of linking/navigation structures. Therefore, "electronic media" is used in this thesis to refer to any media, including text, graphics, video and audio, presented electronically with any type of linking/navigation structure. Similarly, "electronic text" is used in this thesis to refer to text presented electronically with any type of linking/navigation structure. In this research examples of electronic texts include:

- textual information organised as hypertext (nodes connected by embedded links);
- textual information organised in a series of sequential nodes;
- textual information presented as one scrollable document, such as PDF files;
- textual information organised in alphabetical order or as a logical hierarchical contents list where there are no embedded links.

It should also be noted that the focus of this research is on electronic texts where the text content is pre-generated by someone other than the learner, rather than editable text such as that presented in word processors.

2.3.4 Section Summary

In this section, the place of electronic text as an e-Learning technology was considered from a historical perspective and in terms of categories of e-Learning technology. From a historical perspective, the development of the WWW has opened up new opportunities for e-Learning, and it is important that electronic texts in these environments are designed to support effective learning. In terms of Boyle (1997)'s framework of e-Learning technology, educational electronic texts were placed under the category of information dissemination and retrieval. The definitions of hypertext, hypermedia and electronic texts were also discussed and electronic text was taken as a general term to describe any presentation of textual information in an electronic medium.

2.4 Navigation

This section discusses definitions of navigation in electronic environments, navigation metaphors in these environments, and specific issues related to the navigation of electronic texts. These discussions are not focussed on educational environments, but rather consider navigation in generic electronic environments, and specifically electronic texts.

2.4.1 Problems Defining Navigation

"Navigation" in the real world is commonly used to refer to the planning of routes and corresponding movement through a physical environment, be it the sea or land or space. It concerns questions such as "Where am I?", "Where have I been?" and "Where can I go?" (Nielsen, 2000). Important steps in the navigation of physical environments include orienting oneself in the environment, choosing the correct route, monitoring the route, and recognising that a destination has been reached (Downs and Stea, 1973).

In recent years, the use of "navigation" has been extended to encompass movement within electronic environments such as the web (Gamberini and Bussolon, 2001). However, there have been problems clarifying the definition and use of the term in these environments because direct comparisons with real world uses of the term are not always beneficial.

The outcomes of the CHI'97 workshop, "Navigation in Electronic Worlds", highlighted different uses of "navigation" in electronic environments (Jul and Furnas, 1997). Prior to the workshop, participants were asked to produce their own short definitions of navigation. These definitions captured many aspects of navigation. Examples of these definitions included:

- *"Navigation is ... about finding your way confidently and successfully to your goal while discovering fresh delights along the way."* Mark Apperley.
- *"Navigation is the cognitive process of acquiring knowledge about a space, strategies for moving through space, and changing one's metaknowledge about a space."* Laura Leventhal.
- *"Navigation = Wayfinding + Locomotion; 'Knowing where to go' + 'Getting there.'"* Rudy Darken.
- *"Navigation is getting lost."* Jock Mackinlay.

General themes in the definitions included ideas of locomotion, decision-making, a navigational process, and the context or environment in which the navigation takes place. However, no single definition encompassed all of these points.

Several other terms have been associated with navigation activities. Examples of these are detailed in table 2.2. These terms highlight different activities related to navigation in electronic environments and imply different types of navigational goals. For example, during unstructured browsing the users' goal is ill-defined and they make navigational decisions purely opportunistically. During wayfinding, on the other hand, the user has the goal of reaching a specific destination. Exploration, however, represents a different type of goal and is simply concerned with learning about an environment. For the purposes of this thesis, all of these terms are considered to come under the umbrella term of "navigation".

Name	Description	Reference
Unstructured browsing	Serendipitous or purely random browsing	Cove and Walsh (1988)
Exploration	Exploration of information space with the sole aim of creating or enhancing an internal model.	Spence (2003)
General purpose browsing/ Scan browsing	Looking for general items of interest.	Carmel et al. (1992); Cove and Walsh (1988)
Stigmergy	A form of social navigation: scent, recommendation following and clustering.	Dron et al. (2001)
Search oriented browse	Scanning and browsing information relevant to a fixed task/target.	Carmel et al. (1992)
Querying	The description of a specific or general target and automatic translation in information space to where the target is likely to be found.	Spence (2003)
Wayfinding	Movement towards a specific destination.	Passini (1992)

Table 2.2. Terms related to the activity of navigation.

An overall definition of navigation in electronic environments was put forward by Benyon (1998a): "... the activity of finding ones way throughout an environment". This highlights the idea of navigation as an *activity* carried out by a user, rather than a property of an interface, such as a menu bar or map. It is useful in that it is not tied to one specific navigational goal. It also has similarities with a real world definition. Another detailed examination of navigation in electronic environments was given by Spence (1999, 2002, 2003). In this work "navigation" activity is defined as "interactively controlled – and usually iterative – movement" or "translation" in information space (Spence, 2002). This can encompass activities where the goal is very specific or is loosely defined, and so can cover all of the terms detailed in table 2.2.

For the purposes of this thesis navigation activity can be understood primarily according to Spence's (2002) definition. However, to explore the meaning of navigation in electronic environments in more depth, it will be considered further from two perspectives: navigation metaphor and models of navigation activity.

2.4.1.1. Navigation Metaphor

"Navigation" can be seen as a metaphor given to users to indicate the way that an electronic environment can be used. Use of this metaphor is evident in application names such as "Windows Explorer" and "Internet Explorer" as well as in the language used in web browsers such as "go" buttons and "home" buttons. It is closely entwined with a spatial metaphor, where similarities, analogies and comparisons are made between real physical environments and electronic environments.

According to Dahlbäck (1998), there are two important assumptions underlying the navigation metaphor. Firstly, that physical environments and electronic environments are similar enough to make this comparison useful, and secondly that the activity of navigation in electronic environments is similar enough to navigation activity in the physical environment for the metaphor to be valuable. Further assumptions might be that people use spatial skills when navigating electronic environments, for which there is some mixed evidence (e.g. Dahlbäck et al., 1996; Dahlbäck, 2003a; Dahlbäck, 2003b), and that people learn to navigate electronic environments in the same way they learn to navigate in the physical world.

According to Siegel and White (1975), spatial knowledge of the physical world develops in a series of stages: landmark, route and survey knowledge. In landmark knowledge, individuals learn to discern and remember separate landmarks. In route knowledge, landmarks are coordinated into a sequence, resulting in a path or route. Finally, survey knowledge consists of a representation of an entire space including relations between landmarks and routes. Boechler (2001) suggests that survey knowledge in a large hypertext can be achieved through the provision of navigation aids that provide an overview of the hypertext, such as maps and contents lists.

However, the navigation metaphor may be problematic because it encourages comparisons between electronic environments and physical environments. Boechler (2001) suggested that the metaphor may be useful for novice users, for example of hypertext environments, since it encourages them to think about relationships between nodes in the hypertext as if they were physical relationships. But the metaphor may break down as the users become more advanced and notice differences between the hypertext and the physical environment. In fact, it has been argued that navigation is a limited metaphor that potentially constrains our understanding of the way that people interact with electronic environments, particularly with hypermedia and websites (Dillon and Vaughan, 1997). The metaphor encourages designers and researchers to think about interaction and navigation with electronic environments in the same way as they think about interaction and navigation in physical environments, and consequently any issues that are specific to electronic environments may be missed.

Farris et al. (2001) and Farris et al. (2002) describe experimental studies that investigated the appropriateness of the navigation metaphor in hypermedia in terms of how well the metaphor fits with the users' mental models of the structure of a hypermedia system. In these studies participants used a hierarchical hypermedia system with either one, two, three or four levels. They were then asked to produce a hand-drawn map showing the nodes and links in the system they had explored. The results of these studies showed that irrespective of the number of levels in the hierarchical hypermedia they used, the participants' hand-drawn maps revealed that they still had the same understanding of the navigation structure. It was also reported that users' drawings of the hypermedia navigation structure largely reflected conceptual or semantic relationships, rather than the actual links in the hypermedia. These findings suggest that users' may not view hypermedia systems spatially, and these findings have implications for the way that the navigation structure of a system is designed. In line with this, Dourish and Chalmers (1994) suggested that navigation in environments such as hypertext might have a better grounding in a semantic metaphor, where navigational movement is performed because of a semantic relationship (in terms of meaning) e.g. bigger, alike, faster. If users view the structure of a system conceptually or semantically then this conceptual or semantic structure should be reflected in the way that the navigation is designed in the interface. For example the navigation aids should depict the conceptual or semantic structure of the system, rather than trying to impose a spatial organisation.

The consideration of which types of metaphor (conceptual/semantic vs. navigation/spatial) best fits the users' understanding of the system structure indicates that the way that the system "structure" is understood by a user is an important issue in navigation. The studies by Farris et al. above highlight the fact that the users' understanding of the system structure is important in determining whether a navigation metaphor is appropriate. This will be further discussed under the heading of "Information Architecture" in section 2.4.4.

Dahlbäck (1998) also talks about the nature of the electronic environment in determining the utility of a navigation metaphor by looking at the similarities between the physical environment and different types of electronic environments. Since virtual reality (VR) systems preserve most of the spatial properties of physical worlds, the mapping from the physical world to the VR world is relatively straightforward.

However, because the "physics" of hypertext and hypermedia is different, Dahlbäck (1998) suggests that more caution should be exercised when making comparisons between these environments and the physical world.

Benyon (1998a, 1998b) suggests that we should go beyond navigation as a metaphor: "'Navigation of Information Space' is not (just) a metaphor, it is a paradigm shift. Navigation of Information Space is a new paradigm for thinking about HCI, just as Direct Manipulation was a new paradigm in the 1980s". This is an interesting proposal since it suggests that navigation might be a valuable way of thinking about HCI as a whole. Yet, in this thesis it is suggested that this proposition should not be taken to mean that all HCI is navigation, in the same way that not all HCI is direct manipulation. In some spaces navigation is the most important activity, whereas in others it is just one aspect of what is going on (Höök et al., 1998), and not all interaction is navigation. For example entering numerical data into a spreadsheet requires little navigational activity.

This section described navigation metaphors as one perspective on navigation research. However, it should be noted that in this thesis navigation is considered purely from the perspective of the effects of navigation aids on learning. It does not consider the relative merits of the navigation metaphor as a whole in terms of its appropriateness for learning with electronic texts.

2.4.1.2. Models of Navigation Activity

This section considers the activity of navigation in more detail and examines what people do when they navigate in an electronic environment and, in particular, in electronic texts. Some models of navigation activity have considered what people do when they navigate in physical environments (e.g. Downs and Stea, 1973). Other models have detailed navigation activity in VR environments. For example, Kaur (1998) describes the "Explore Navigate Model" as part of a theory of interaction in VR environments. The key activities in this model are: "scan", "plan" and "navigate". During "scan" the user inspects the current state of the VR environment from the available cues in the interface. During "plan" the user determines an appropriate plan of further activity from an inspection of the environment, with respect to searching for a target or an intention to explore. During the "navigate" phase the user moves themselves to a location elsewhere in the VR environment, following plans from the previous stage. However, since this model is primarily concerned with navigation in VR environments, it may not be generic enough to capture the details of navigation activity in electronic texts.

Building on his work from the CHI '97 workshop, Spence (2002) presents a framework for the activity of navigation (see figure 2.2), and uses the term "translation" to describe movement in information space. In this model of navigation activity, a user iteratively browses content, forms an internal mental model of this content, makes an interpretation of the model, selects a means of making a translation in the information space, and then makes that translation. The ovals in the diagram represent activities and the boxes represent the outcomes of these activities (deBruijn and Spence, 2000). In terms of electronic texts, since this framework has no strict relation to a physical environment, or a particular type of electronic environment, it is suited to describing navigation activity in electronic texts, where the relationship between pages is usually conceptual or semantic, rather than spatial.

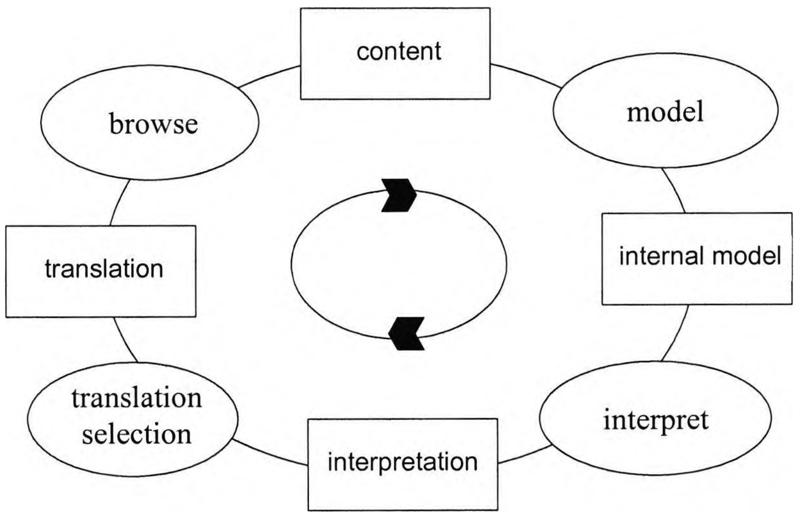

Figure 2.2. A framework for navigation. From Spence (2002).

It seems that the most important part of the framework for educational electronic texts is the development of an internal model of the content of the text, since an understanding of the text content should be the learner's primary goal. In Spence (1999) it is implied that there may be different aspects to the internal model developed during navigation. For example, Spence suggested that during social navigation (navigation activity where other navigators are also involved) two distinct, but inter-related, internal models may be involved: one for information and the other for social aspects. In learning with electronic texts the learner has to develop knowledge as well as navigate through the system. Hence, it has been argued that the learner has to develop and update two parallel internal models (Brunstein et al., 2004; Suzuki et al., 2001). Firstly, the learner has to develop a representation of what the text is about as the main processing goal. Secondly, they need to know how to navigate within the system. The fact that these two internal models need to be maintained may have implications for the allocation of cognitive resources and cognitive load during learning with educational electronic texts. This is discussed further in the next section (section 2.4.2).

2.4.2 Disorientation, Cognitive Load and Navigating Electronic Texts

The freedom and flexibility offered when navigating in hypertext systems have been put forward as the main strengths of these types of system (Otter and Johnson, 2000). As a result of this freedom and flexibility, the user is responsible for decisions about what information to access and the order in which to visit it (Boechler, 2001). However, it also follows that the users' cognitive resources must be allocated to several tasks at the same time which may result in increased cognitive load.

According to Sweller (1988), "cognitive load" is the burden that a particular task imposes on the cognitive system. In terms of learning, cognitive load theory proposes that the limited capacity of working memory has important implications for the development of knowledge (Chandler and Sweller, 1996). Working memory can be affected by two main types of cognitive load: intrinsic cognitive load and extraneous cognitive load. Intrinsic cognitive load is determined by the demands of a task (Chandler and Sweller, 1996). Extraneous cognitive load, on the other hand, is generated by the format of information (Chandler and Sweller, 1996), and any additional activities an individual is required to do over and above their main task. If extraneous cognitive load is kept to a minimum, and intrinsic cognitive load is not too high, then there may be working memory available for the development of knowledge (Garner, 2001).

When navigating in electronic texts, one of the symptoms of high cognitive load is disorientation (Boechler, 2001) and feelings of "lostness". There have been several accounts of users becoming lost (Stanton et al, 2000; Conklin, 1987; Kim and Hirtle, 1995; McDonald and Stevenson, 1998) or disoriented in hypertext systems (Calvi, 1997; McDonald and Stevenson, 1996). According to Witt and Tyerman (2002) "a user becomes disoriented when they lose track of where they are, or when pages are complex, contain unexpected content, or include internal and broken links". In addition, Edwards and Hardman (1989) reported three categories of feelings of lostness: 1) the user does not know where to go next; 2) the user knows where to go but not how to get there; and 3) the user does not know where they are in relation to the overall structure of the document.

As discussed in section 2.4.1.2, in learning with educational electronic texts the learner has to develop and update parallel mental representations: one concerning the text content, and one concerning how to navigate the text (Brunstein et al., 2004; Suzuki et al., 2001). Brunstein et al. (2004) therefore suggest that the structure of the system should be constructed to match the structure of the content, be it conceptual or spatial, to minimise the burden of dual representations. The focus of instructional materials should be on the instruction itself; information that is outside the instruction, such as the navigation aids, should be designed to minimise extraneous cognitive load (Feinberg and Murphy, 2000).

Although much research has discussed the relationship between navigation and cognitive load (e.g. Boechler, 2001; Brunstein et al., 2004), little research has actually measured the effects of navigation on cognitive load. One attempt made by Eveland and Dunwoody (2001) to measure cognitive load involved measuring learners' subjective ratings of the difficulty in recognising the organisation and structure of information associated with different types of electronic and paper based texts. However, as Eveland and Dunwoody pointed out, this may not have been the best measure of cognitive load. Alternative measures of cognitive load include dual task performance, learning performance, psychophysical measures such as heart rate variability, and event related brain potentials (Paas and Merrienboer, 1993; Paas et al. 1994; Dennis et al, 1998; Murai et al., 2004).

Disorientation and cognitive load are issues that were identified in early hypertext research, but continue to be unresolved (Boechler, 2001). However, one possibility that has been put forward for reducing cognitive load, and disorientation, is providing navigation aids that give an overview of the electronic text, such as maps, contents lists, or A-Z indices (Brunstein et al., 2004); navigation aids are the focus of the next section of this discussion.

2.4.3 Navigation Aids in Electronic Texts

In this thesis, navigation aids in electronic text are defined as elements of an interface that aid the access and traversal of the text. The following categorisation is used in this research.

- *Non-interactive navigation aids* – any non-interactive aid presented to a user to help them navigate a system. Examples include paper maps, non-interactive electronic maps or non-interactive content lists displaying a list of nodes in the electronic texts. A sub category of non-interactive aids is "orientational" aids (Brunstein et al. 2004). These explicitly display the structure of the system content and tell the user where s/he is within the system.

- *Interactive navigation aids* – interface mechanisms that allow the user to access information within an electronic text. These can be further broken down into singular or aggregate navigation aids and static or dynamic navigation aids. It should be noted that these categorisations are not mutually exclusive.
  - *Singular navigation aids* – interactive navigation aids that allow users access to a single location at any one time. Examples in electronic texts include: home buttons, paging buttons, back-track and forward-track buttons, open buttons, thumbnail links and embedded links.
  - *Aggregate navigation aids* – a cluster of interactive navigation aids grouped together on the interface that offer the user access to a number of locations. They give an overview of the electronic text content and may be localised, in that they only show nodes that are directly linked to a given page, or they may be global, in that they show all the pages in an electronic text. Examples include: menu bars, contents lists, A-Z indices, breadcrumb trails, maps (including spatial maps that depict the link structure of the electronic text, and conceptual maps that depict the key concepts in the electronic text and their relationship), guided tours, favourites or bookmark menus, and history lists.
  - *Static navigation aids* – navigation aids where the location that they offer access to is fixed. Static navigation aids can be either singular or aggregate navigation aids. All of the above examples of singular and aggregate navigation aids are also examples of static navigation aids.
  - *Dynamic navigation aids* – navigation aids where the locations offered change, or the configuration (layout) of the navigation aid changes. These changes can be based on direct user actions or can occur automatically (e.g. due to some intelligent agent). They can also be singular or aggregate navigation aids. Examples of these navigation aids include (this is not meant to be an exhaustive list):
    - *Dynamic singular navigation aids where the locations change due to user actions* e.g. scroll bars, address bars, and search/query bars.
    - *Dynamic singular navigation aids that change their configuration automatically* e.g. embedded links in an electronic text that change based on an intelligent agent and "Stigmergy" links that

increase in size based on their popularity (Dron et al., 2001; see section 2.5.1 for more details).

- *Dynamic aggregate navigation aids where the locations offered change due to user actions* e.g. maps, contents lists or A-Z indices where the user is able to add or delete pages from the aggregate navigation aid.
- *Dynamic aggregate navigation aid where the locations offered change automatically* e.g. a navigation aid that uses rapid serial visual presentation (RSVP). In RSVP a number of chunks of content are rapidly displayed for a brief period of time so that the user can browse through them (e.g. deBruijn and Spence, 2000). An envisaged example of a dynamic aggregate navigation aid that uses RSVP in electronic texts would be an area of an interface that displays a continually scrolling list of interactive page titles. Clicking on the page title allows access to that particular page.
- Dynamic aggregate navigation aids that change their configuration due to user actions could be maps or contents lists where the user is able to change the layout of the navigation aid according to their own preferences.

It is difficult to define one all-encompassing categorisation since new types of navigation aids are being developed all the time. The above categories represent one possible means for classifying navigation aids in electronic texts that is used in this research. See appendix 2.1 for illustrations of the example navigation aids given in this section. Further categorisations are also addressed in this thesis in the framework of constructivism and navigation in terms of how navigation aids affect learning.

2.4.4 Information Architecture

Another issue that is related to navigation in electronic texts is information architecture, sometimes referred to as "system structure" or "system organisation". The "information architecture" refers to the underlying structure of a system (Brink et al., 2002), and determines how the nodes in an electronic text system are connected to each other. For example, the nodes may be connected in a hierarchical structure or in a network structure.

Attendees at the CHI '97 workshop discussed different types of structure that need to be considered in navigational design (Jul and Furnas, 1997). They identified three levels of structure:

- the inherent structure of the information;
- the imposed structure (the structure that is presented to the user, for example through navigation aids);
- the users' cognitive map[2].

According to Jul and Furnas (1997), an example of the inherent structure of information, is the physical structure of files and network topology on the WWW. This is the information architecture of the system as defined by Brink et al. (2002). The links that are displayed to the user provide the imposed structure. Since there are often several possible link structures, Jul and Furnas suggest that there may be several possible imposed structures. This is usually the aspect of the structure which is navigated and concerns the type of navigation aids. Finally, according to Jul and Furnas, each user has their own cognitive map of the information they have navigated and this includes details of how the information navigated relates to specific tasks or topics.

However, in this thesis, with regards to educational electronic texts, in particular, one further aspect of the information architecture is considered important: the inherent conceptual structure of the text content. This may differ from the physical structure described in Jul and Furnas (1997). In educational electronic texts the way that the conceptual structure is conveyed in the imposed navigational structure, or in other words the navigation aids, is of utmost importance in determining how well learners understand the content of the text. Experimental research into these issues will be considered in section 2.5.2.

2.4.5 Section Summary

This section discussed the meaning of navigation in electronic environments. The definition and framework for navigation offered by Spence (2002) is used in this thesis as a context for understanding navigation activity. Since this definition does not rely heavily on models of navigation in physical environments, it is appropriate for describing navigation in electronic texts. The problems of disorientation and cognitive load in navigation were discussed and Brunstein et al. (2004) suggested that navigation aids that show an overview of the electronic text, such as maps or contents lists, may

[2] A 'cognitive map' is a popular term for people's mental representations of environments that reflects spatial relations among elements (Tversky, 1993) and is often assessed through hand-drawn representations.

help alleviate these problems. Possible categorisations of navigation aids were presented and important aspects of information architecture were also discussed in this section. These discussions highlighted that the way that the interface is designed to support the activity of navigation (i.e. the navigation aids that are provided) is important, particularly in educational electronic texts, since it is the aspect of the system that the learner sees and bases their internal model on. The navigation aids also have implications for the level of cognitive load associated with navigating the electronic text. In educational electronic texts, if cognitive load is high then it reduces the amount of cognitive resources available for understanding the text content and learning.

2.5 Navigation Aids and Learning

This section examines previous research on navigation aids and learning and presents examples of applications developed with the specific aim of supporting navigation in educational electronic environments. Research into the effects of navigation aids on learning with electronic texts is also described.

2.5.1 Navigation Support for Education

Several attempts have been made to support navigation in educational environments. Navigation support tools are applications specifically designed to support navigation in educational environments, such as on the WWW, and can provide a number of navigation aids. They sit on top of the educational content in a similar way to WWW browsers. This section presents examples of navigation support tools along with the results of some preliminary evaluations performed by the tool designers.

2.5.1.1. Navigation Path-Planning Assistant

Researchers at the Toyoda Lab at Osaka University, Japan, have created tools to support navigation specifically within educational hypermedia environments. The work at the Toyoda lab can be divided into two main approaches. The first of these is the Navigation Path-Planning Assistant (Kashihara et al. 2000a; Kashihara et al. 2000b; Suzuki et al., 2001; Hasegawa and Kashihara, 2004). The second is the Interactive History List and is described in section 2.5.1.2.

The Navigation Path-Planning Assistant is a navigation support tool that helps learners to achieve their navigation goals (e.g. finding information, exploring information) by supporting them as they plan their navigation paths (Suzuki et al., 2001). Suzuki et al. argue that due to the complexity of hyperspace, learners often fail to complete their navigation path, as they do not know which link to follow to achieve their exploratory learning goals. As discussed earlier in relation to cognitive load and navigation (see section 2.4.2), Suzuki et al. argue that when learners navigate an educational electronic text they have to make concurrent cognitive efforts: decisions about their navigation path (e.g. where to go); decisions about their learning goals; and comprehending the content of the electronic text. Accordingly, the navigation path-planning assistant aimed to provide learners with a planning space, consisting of a path previewer, a page previewer and a resource map, to allow learners to "see through" hypermedia learning resources to make a navigation path plan, without visiting each page in the hypermedia (see figure 2.3).

Figure 2.3. Navigation Path Planning Assistant. From Kashihara et al. (2000a). The left-hand window shows the content of the hypermedia page currently being displayed. The right-hand window is the path planning assistant consisting of: the page preview window; the map window; and the path preview window.

In order to empirically evaluate the effectiveness of the path planner, measures of learning (problem solving scores) and navigation (number of page revisits) were taken (Kashihara, et al. 2000a; Suzuki et al. 2001). The effects of navigation with and without the use of the planning assistant, in simple (few nodes) and complicated (many nodes) hypermedia systems were assessed using these measures. The overall findings suggested that the tool significantly facilitates learning and navigation especially in a more complicated hyperspace.

2.5.1.2. Interactive History List

The second application developed at the Toyoda lab is the Interactive History List (Kashihara et al. 1999; Kashihara et al. 2000c; Kashihara et al. 2000d; Kashihara et al. 2001). Kashihara et al (1999) propose that the history list provides reflection support during navigation in educational hypermedia. Each time a user navigates from one page to another in the hypermedia the history list requests that they select an exploration goal. The tool then creates an annotated history list from this information and a knowledge map of the hypermedia pages the user navigates. The Interactive History List consists of: a window where users enter their exploration goals; an annotated exploration history list; and a knowledge map. Figure 2.4 shows an example for a hypermedia on the topic of the occurrence of earthquakes. In this example the user selects their exploration goals from a drop down list in the "exploration goal input" window as they navigate from one page to another. Here they can select from the following exploration goals: "Supplement", "Elaborate", "Compare", "Justify", "Rethink" and "Apply". These goals then appear as annotations on the history list. The knowledge map is then generated from the exploration goals entered. For example, where the exploration goal is to elaborate on the content of a starting page by examining the content of another, the knowledge map represents the target page being within a "set" of the starting page. In figure 2.4 a user has navigated from the page "The Mechanism of the Occurrence of Earthquake" to the page "Kind of Earth Faults" with the goal to elaborate information. This information is then automatically represented on the knowledge map; the page "Kind of Earth Faults" is shown as an ellipse within an area entitled "The Mechanism of the Occurrence of Earthquake".

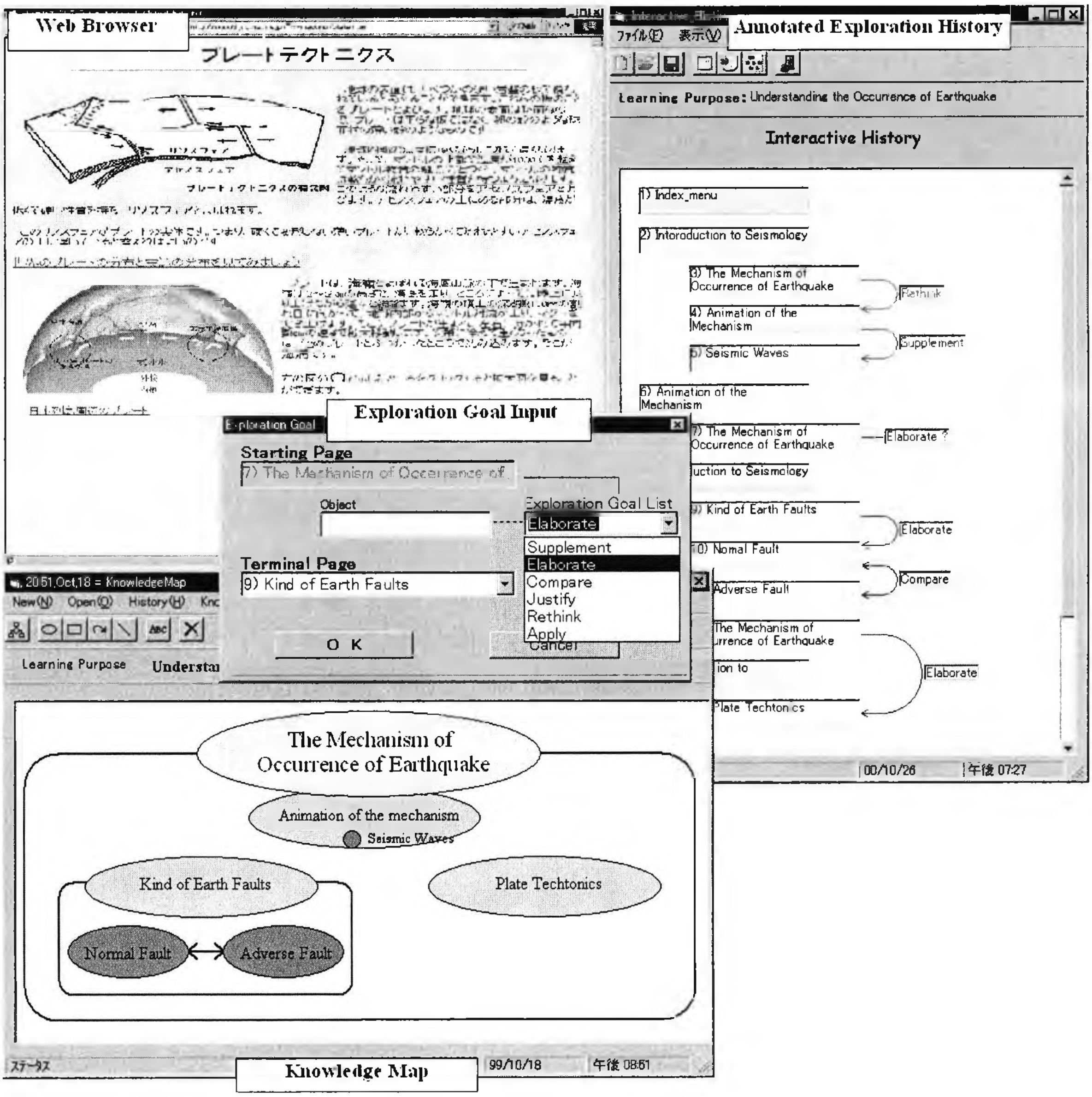

Figure 2.4. The user interface for the Interactive History List. From Kashihara et al. (2001). The Web Browser shows the content of the hypermedia currently being displayed. The Exploration Goal Input window allows the user to input their exploration goals. The Annotated Exploration History shows the learners' history list with annotations. The Knowledge Map shows the map automatically generated from the exploration history.

Kashihara et al. (2000c) argue that the act of inputting an exploration goal encourages students to reflect on the meaning of the links they follow during navigation. In addition, they propose that the knowledge map also encourages reflection on the structure of the information in the content domain, and can be used after navigation has finished. Also, students can revisit the information they have navigated using the history list. Kashihara et al. (2000c) argue that the tool is a potential support for constructive learning with hypermedia.

Preliminary evaluations of the Interactive History List are reported in Kashihara et al. (2000d) and Kashihara et al. (2001). In order to discover the "utility" of the tool the results of a number of measures are described in these papers. These measures include: dispersion of pages visited; no. of revisits per page; no. of target nodes found; and the no. of page revisits while the user searches for a target node. However, the overall purpose and details of these measures are not explained in either Kashihara et al. (2000d) and Kashihara et al. (2001), and how they reflect the "utility" of the tool is not clear. The measures of learning consisted of problem solving scores.

The use of the Interactive History List was analysed with a simple (fewer nodes) and a more complicated (many nodes) hypermedia as compared to use of the hypermedia without the history list. Overall, Kashihara et al. (2000d) and Kashihara et al. (2001) claim that the results show that the interactive history list makes learners' exploration "more intensive" and that it has beneficial effects on learning, particularly in a more complicated hyperspace. Also, they argue that since half of the pages visited were related to exploration goals, the history list affords rethinking each of the exploration processes and their relationships. However, a lack of inferential statistics reduces the power of these conclusions, since it cannot be determined whether the results for the system with the interactive history list are significantly different to the results for the use of the hypermedia on its own.

2.5.1.3. CoFIND

CoFIND (Collaborative Filter In N Dimensions) is a continually evolving system, whose proposed purpose is to replace the role of the teacher in structuring and selecting learning resources (Dron et al., 2001). Dron et al. argued that this might be achieved through the application of a process named "stigmergy". This term, borrowed from zoology, refers to the behaviour of termites as they build mounds of mud. When the termites start to build mounds they randomly drop lumps of mud. However, the presence of a mud heap encourages other termites to also drop their mud in this location. Dron (2004) used stigmergy to describe a certain type of social navigation, where people tend to cluster together around a particular point of interest. CoFIND attempts to imitate this property found in natural environments and apply it to electronic environments.

In a hypermedia environment, CoFIND is used to alert adult learners to the potential relevance of topics through the size of the link to information on that topic. Every time a link to a particular topic is traversed by a learner, the size of the link to that topic increases, whilst other links on the same screen decrease in size. Dron et al. (2001) propose that through this activity a process of self-organisation occurs, where resources related to topics of potential high importance and relevance would be highlighted to learners.

Although no formal evaluation was reported, when CoFIND was used in a classroom setting, it was noticed that this system could be subject to anomalies, where information of low relevance and importance could gain high emphasis. For example, Dron et al. (2001) report that a student, when adding his own topic to the list, repeatedly clicked on his topic label over a period of a few minutes immediately after adding it. This led to the link gaining in size and relative prominence, even though the topic was of marginal interest to the course. Nevertheless, despite this potential problem, the overall intention of CoFIND may be a useful aid in an educational setting, but the use of CoFIND is yet to be fully evaluated.

2.5.1.4. Nestor Navigator

Nestor Navigator (see figure 2.5) is a navigation support tool that is an "integrated navigation aid", combining navigation aids such as interactive graphical overviews, annotations and concept-maps (Zeiliger et al. 1997). It is a web browser and is used in the experimental studies presented later in this thesis in chapters 4, 5 and 6. Elkund et al. (1999) argue that web navigation relies, more than other media, on a personal construction of what is meaningful. In other words, the user must abstract relevant information from the web and construct meaning from it. Taking this into consideration, Zeiliger et al. (1999) and Esnault and Zeiliger (2000) propose that navigation support should occur in a "constructivist environment" – an environment with means for gathering, representing, externalising, structuring and creating navigational objects.

Nestor is an add-on to a standard Microsoft Internet Explorer (IE) browser, in that it uses the IE browsing engine, although a browsing window is available within the tool and may be used instead of the IE browsing window.

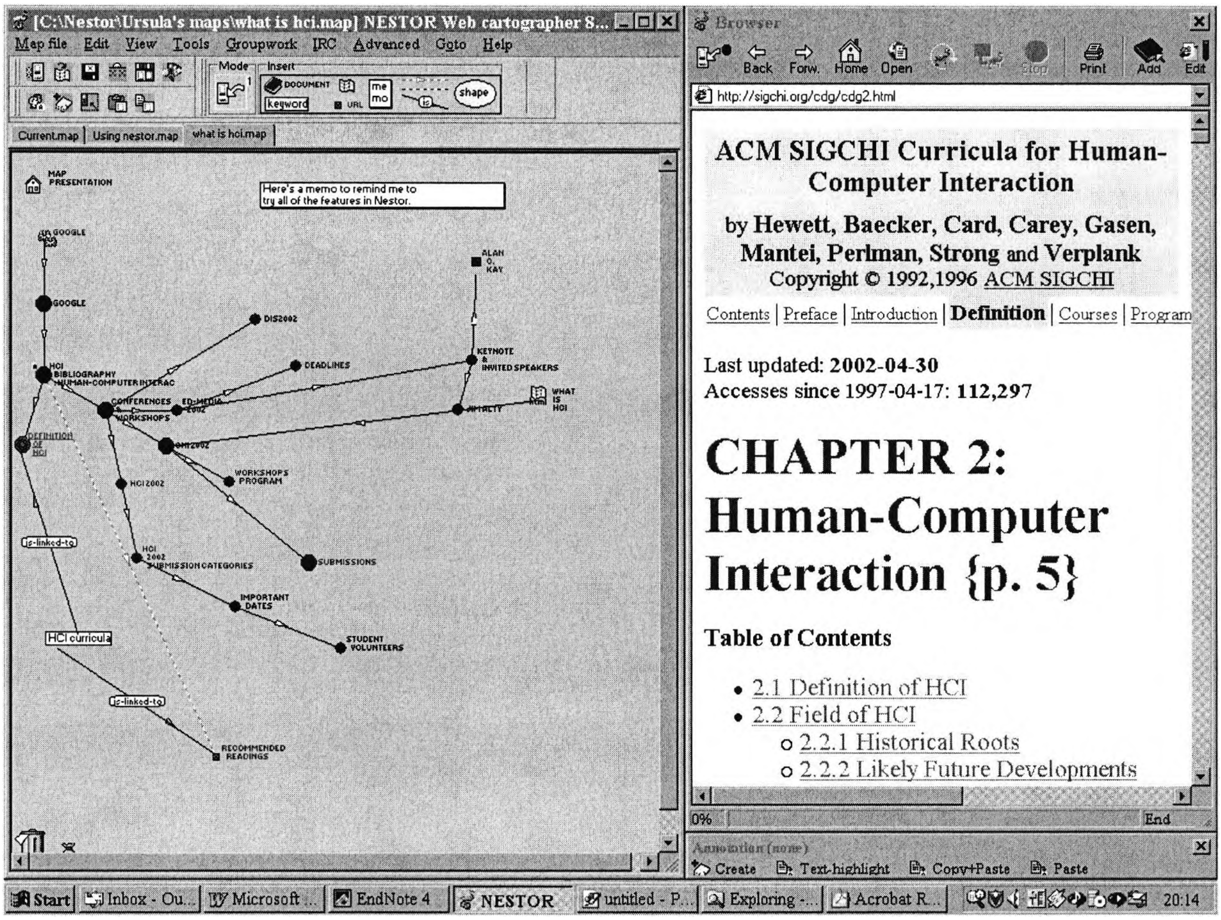

Figure 2.5. The Nestor Navigator browser. The right-hand window shows the content of the web page and the left-hand window shows a "map" of the web pages visited.

As the user navigates, Nestor draws a graphical trace of the web pages visited, thereby portraying the navigational experience. Each visited web page is shown as a circle, whose size is dependent on the number of departing links on the page, or as a square when there are no departing links. Visited links are represented as arrows between the connected web pages.

The graphical trace, or "map", is interactive. By clicking on the corresponding circle or square the user can access visited web pages. Zeiliger et al. (1999) argue that these maps increase the visual feedback in navigation and aid orientation. In addition to this experiential trace, users can create and add personal web pages and personal links to the map. Annotations can also be added to visited web pages and can include text and links. These annotations are displayed whenever an annotated page is revisited. Zeiliger et al. (1999) propose that these annotations help the user reflect on their navigation and structure their thoughts. Also, thought structuring is aided further by the fact that users can insert keywords, memos and labelled relations between keywords. The maps produced can make the conceptual structure of the domain, as created by the learner, clearer and as such easier to navigate.

To help structure the maps, conceptual areas can be created. Visited web pages can be placed in these, so that when the area is moved they move with it. The conceptual areas can also be collapsed and expanded. Guided tours can be created by selecting paths on the map. Web pages on the tour can then be revisited in the order specified. Navigational information, such as URLs or whole maps can also be shared and published by groups of people. Nestor users are notified whenever they visit a URL that has been published by one of their colleagues, and any annotations attached to the page by the publisher are shown. The map is shown in the context where the publisher accessed the document. Although this cannot be modified, it can be navigated. Maps can also be exchanged through asynchronous communication.

Nestor Navigator can also be used to create other navigation aids, such as contents lists, or A-Z indices. The links between the visited pages can be turned off so that the users are only presented with the page titles of the visited pages. These page titles can then be rearranged according to the users' preferences, thereby allowing them to create contents lists or A-Z indices.

An initial evaluation of the use of Nestor in an educational setting aimed to examine whether visualising navigational experience aids users' "practical orientation" (Zeiliger et al. 1997). Learners were asked to use a hypermedia on the topic of "Audio-Visual and Learning" to select arguments to support a learning task where they had to analyse a cartoon. The measures included performance on the learning task, navigation operations (use of embedded links, the back button and Nestor maps to navigate) and the learners' computer literacy and knowledge of the audio-visual topic was assessed through a pre-test. The results suggested that students with higher computer literacy used Nestor's facilities more. Novice navigators, on the other hand, seemed to rely on standard WWW navigation aids such as the back-button, forward-button and embedded links. However, high educational task scores were not correlated with intensive use of Nestor. It was also found that usability problems were frequently reported in post-test questionnaires completed by the students, but details of these problems were not given in Zeiliger et al. (1997).

Zeiliger et al. (1999) performed another investigation where the aim was to discover why users revisit web documents so often, even when a map is available, suggesting that they may have expected the map to reduce this behaviour. During this investigation students were asked to find information on the web and answer questions. Measures included navigation operations (total operations, revisits, use of embedded links, use of Nestor maps, use of the back button, use of the forward button, use of the address bar, and use of the home button) and interviews with the learners after they had used Nestor. The results of this indicated that the use of the map was high, especially as compared to back button usage. Nevertheless, during interviews after the main experimental sessions, students reported that they were disoriented by the way that information was presented in the web pages. From this information, Zeiliger et al. (1999) suggest that the explanation for the frequent revisits can be framed in terms of “conceptual” disorientation, as opposed to “practical” disorientation observed in navigation. However, the exact meanings of these terms are not explained.

In sum, Nestor is an interesting example of a web navigation tool that has been specifically designed with educational use in mind. It is particularly significant to this thesis research since it was built with the aim of supporting constructivist learning. Although some preliminary evaluations have been carried out, there is room for more thorough investigations of how Nestor, and the navigation aids it offers, affect learning, particularly in terms of evaluating whether this constructivist approach to navigation support is beneficial.

2.5.2 Experimental Research on Navigation Aids and Learning

This section presents a review of experimental research on the effects of navigation aids in educational electronic texts on learning. A focus is placed on studies that compare popular aggregate navigation aids such as A-Z indices, contents lists and maps with singular navigation aids in plain hypertext (embedded links) and paging buttons. Studies in this area differ in the particular types of navigation aids and electronic texts used in the investigations. The results of the investigations also vary.

As discussed in chapter 1, many studies in HCI have considered the utility of navigation aids in terms of navigation performance and have produced mixed results (Gupta and Gramopadhye, 1995; Nilsson and Mayer, 2000; Danielson, 2002). However, in e-Learning environments it is the effects of navigation aids on learning that are most important.

Several experimental studies have examined the effects of maps on learning with electronic texts. As discussed briefly in chapter 1, the findings of these studies have also had mixed results. Some studies found that the maps have no effects, or even have negative effects, on navigation performance and learning. For example, Wenger and Payne (1994) compared the effects of a system where a graphical map was provided with the effects of a system of plain hypertext where no map was provided. They found that although the provision of a map increased the number of nodes read and reduced the number of nodes revisited during reading, it had no effect on recall or comprehension of the text content. Similarly, Stanton et al. (1992) also compared the use of an electronic text with a map to a system of plain hypertext with no map provided. They measured the effects on learning (sentence completion tasks and quality of cognitive maps), perceptions of the system (lostness, ease of understanding, control over information and usefulness of maps) and navigation performance (number of pages visited, "secondary links" used, different pages visited and map use). They found that a map resulted in a lower number of different pages visited and a lower number of "secondary links" used, lower perceived control and poorer development of cognitive maps as compared to a condition with no map present.

In contrast, in other research, maps have been found to have positive effects on learning, and some types of map have been found to be more beneficial than others. Dee-Lucas and Larkin (1995) compared the use of electronic text with paging buttons to both a hierarchically organised map of the text content and an A-Z index overview. They measured learning in terms of their participants' ability to summarise the text and their memory for text topics. They also examined navigation in terms of the time participants spent reading the electronic text and the proportion of pages in the electronic text that were viewed. They found that both the map and the A-Z index led learners to remember significantly more of the text topics and to demonstrate better breadth of recall than the text with paging buttons. The differences in the navigation measures were not significant.

McDonald and Stevenson (1997a) present a study that aimed to empirically evaluate the usefulness of a group of popular navigation aids in an educational electronic text on the psychology of human learning. They examined the effects of a localised "spatial map" (see figure 2.6), a contents list and plain hypertext on navigation performance and on participants' ability to represent the document structure as a hand-drawn cognitive map. The localised spatial map showed the link structure of the document and was specific to the area of the hypertext system that the learners were currently visiting. Both the contents list and the spatial map were non-interactive and the learners simply navigated using the embedded links in the text.

As they used the electronic text, the participants were asked to find the answers to a number of questions about the text content, where the answers could be found in specific nodes in the text. The navigation performance measures included the number of nodes opened during reading, and number of additional nodes accessed per question (over and above the number of nodes that would be accessed if the participants took the most direct route to the node where the answer to the question could be found). In the cognitive map task the participants were given a numbered alphabetical list of node titles in the document and were told to put the numbers corresponding to the node titles in the correct places on an outline map. The cognitive maps were scored by the number of correctly placed node-titles. Overall, navigation performance of participants in the map condition was better than those in the contents list condition, which in turn, was better than those in the plain hypertext condition. Participants in the map condition produced more accurate cognitive maps than those in the plain hypertext condition, who in turn produced more accurate maps than those in the contents list condition.

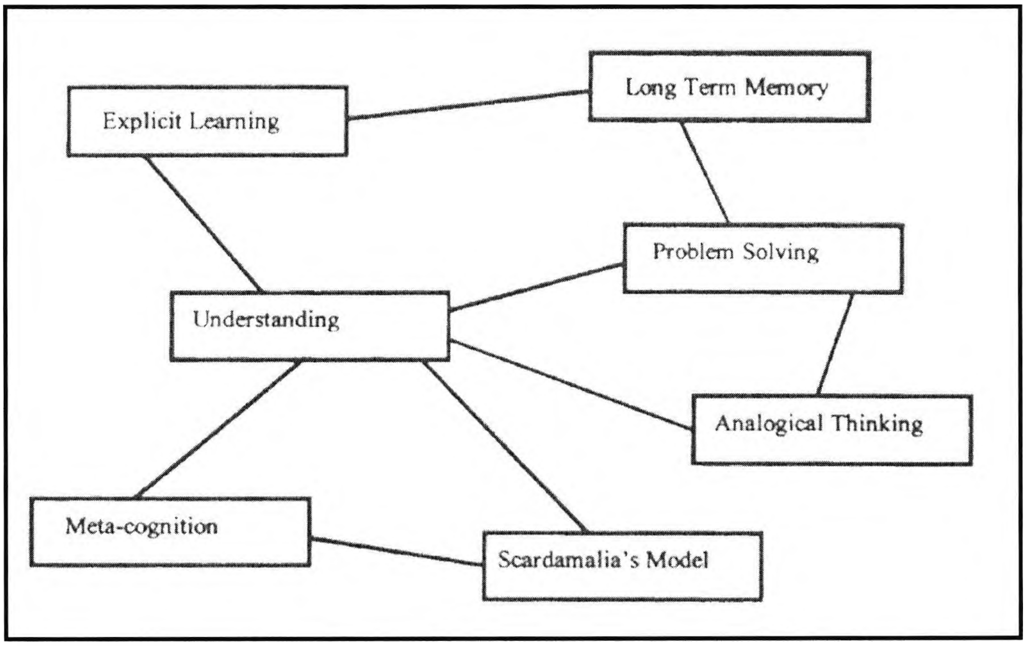

Figure 2.6. An example of a localised spatial map. From McDonald and Stevenson (1999). The boxes represent pages in the text and the lines represent embedded links between the pages.

Similar to the study in McDonald and Stevenson (1997a), a first experiment in McDonald and Stevenson (1999) assessed the effects of a localised spatial map, a contents list and plain hypertext on navigation and learning measures. Again the participants used an electronic text on the psychology of human learning and were asked to find the answers to a number of questions on the text content, where the answers could be found in particular target nodes in the text. The navigation measures were: time to locate target nodes and the number of additional nodes opened. The learning measures were: the number of questions correctly answered while participants used the text and the number of node titles correctly recalled. The results of this experiment showed that a spatial map facilitated navigation performance more than a contents list, which in turn was better than plain hypertext. However, for the learning measures the findings were different. There were no significant differences in the number of factual knowledge questions correctly answered while the participants used the electronic text. Furthermore, participants in the spatial map and contents list conditions performed significantly better than participants in the hypertext condition in terms of the number of node titles recalled. Overall, in both of these studies the findings suggest that spatial maps, in particular, had benefits for navigation performance and some learning measures.

A second experiment presented in McDonald and Stevenson (1999) and in McDonald and Stevenson (1997b) aimed to examine the effects of a localised "conceptual map", a localised spatial map and plain hypertext on navigation performance and learning. As in the previously discussed experiments, a localised spatial map simply shows the structural properties of an electronic text and shows which page is linked to which other pages for a certain area of the text. A localised conceptual map, in contrast, simply identifies the key concepts in the text and specifies the relations between them for a localised section of the electronic text (see figure 2.7). Learning was measured in two testing sessions, one immediately after using the electronic text (immediate testing) and the other a week later (retention test). The aim was to examine the effects on learning over time. The navigation measures in this experiment were the time spent reading, the mean time to locate the target node, and the number of additional nodes opened. In both testing sessions, learning was measured through factual and "main ideas" questions. The factual questions required the learner to recall information from a single node in the electronic text. The main ideas questions, in contrast, required the learner to integrate information from a number of nodes in the electronic text.

The findings showed that spatial maps facilitated navigation more than conceptual maps and plain hypertext. However, another pattern emerged for the learning measures. For the factual knowledge questions, the spatial and conceptual maps facilitated learning compared to plain hypertext on the immediate test. However, on the retention test a week later, the conceptual map maintained this facilitation, as compared to the other two conditions. For the main ideas questions, examining the findings for the two experimental sessions *together* revealed that the conceptual map was more beneficial than the hypertext, which in turn was more beneficial than the spatial map. However, looking specifically at the findings for the immediate testing session, the conceptual map and hypertext did not differ in their effectiveness. Overall, McDonald and Stevenson (1999) suggest that these findings indicate that spatial maps are more effective than conceptual maps and plain hypertext in terms of navigation performance. On the other hand, in terms of learning, conceptual maps are more beneficial.

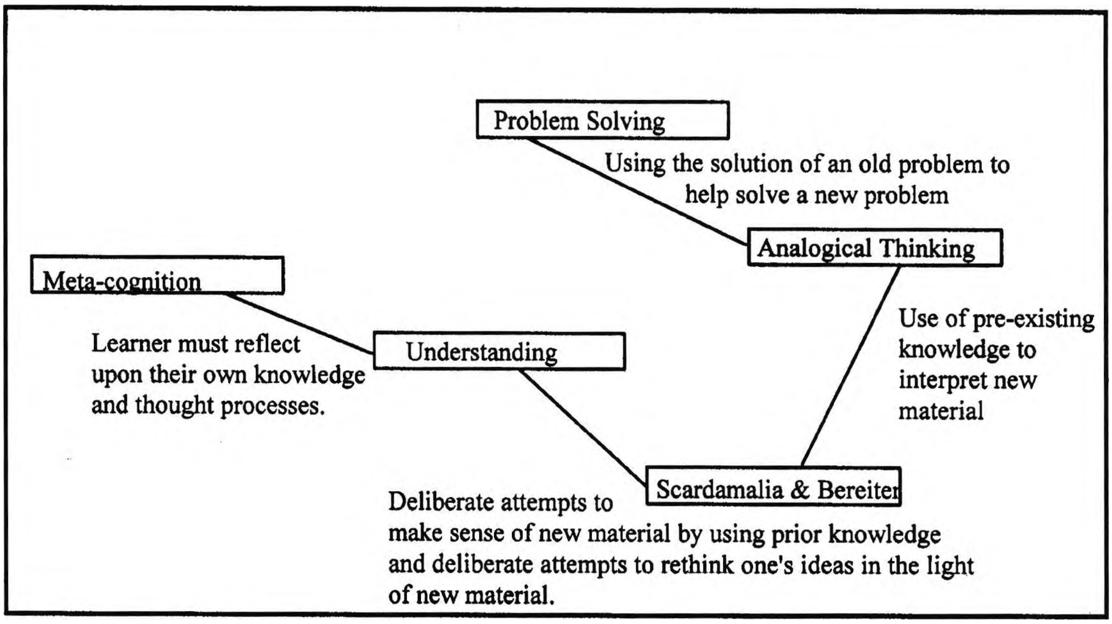

Figure 2.7. An example of a conceptual map. From McDonald and Stevenson (1999).

Other research has shown that some aggregate navigation aids are more beneficial in terms of learning than others. Simpson and McKnight (1990) compared the influence of an A-Z index and a hierarchical contents list on participants' navigation through a hypertext document (number of additional nodes opened over and above the most direct route to a target, and contents list/A-Z index usage) and their structural knowledge of the document (accuracy of hand drawn maps of the text content). They found that hand-drawn maps produced by participants using the hierarchical contents list were more accurate than those produced by participants using the A-Z index. They also found that the participants in the contents list condition opened fewer additional nodes and used their contents list more than participants in the A-Z index condition.

More recently, Puntambekar et al. (2003) compared the effects of maps and an A-Z index as navigation aids in an educational hypertext. To measure navigation they assessed the extent to which their participants used the map, or A-Z, compared to embedded links and evaluated participants' navigation paths through the text. They measured learning through an essay task and a concept mapping task and also measured the participants' attitudes about how useful the electronic text was in a questionnaire. Puntambekar et al. found that the map led to significantly better performance in the essay task and the concept mapping task and that the learners' navigation in this condition was more focussed (as seen by the navigation paths) than those who were given an A-Z index. They also found that learners' responses to the attitude questionnaire showed that they found the maps helpful for finding information relevant to their goals.

The results of studies by McDonald and Stevenson highlight the benefits of maps as navigation aids, and suggest that maps that show the conceptual structure of an electronic text are particularly important for learning. Nevertheless, in the experiments discussed here, the majority of learning measures assessed learning only in terms of performance measures. These measures do not take into account the learners' engagement with the text during reading. There were also no measurements taken concerning the learners' feelings about their learning with the electronic texts. These issues are also important to the learning process. In addition, a problem with the McDonald and Stevenson studies is that the aggregate navigation aids investigated were non-interactive. This does not reflect aggregate navigation aids in modern electronic texts.

Overall, these studies highlight that the effects of navigation aids on learning are complex. The focus of this review was on comparisons amongst common navigation aids such as maps, contents lists, A-Z indices, plain hypertext, and paging buttons. This review also highlighted that future investigations should examine more recent developments in navigation support and should consider all aspects of the learning process, rather than just performance measures. In chapter 3 additional experimental works on the effects of navigation aids and learning, other than those reviewed here, are also considered in specific relation to themes in the framework of constructivism and navigation.

2.5.3 Section Summary

This section presented a review of recent developments in navigation support for educational environments and experimental research into the effects of navigation aids on learning with electronic texts. The review highlighted that new developments in navigation support present some interesting ideas, especially in relation to navigation in a constructivist environment. However, although some preliminary evaluations of the tools have been conducted, it is apparent that the concepts behind each of the tools are yet to be fully evaluated. The experimental studies showed that investigations into the effects of navigation aids on learning have yielded mixed results, suggesting that further research is needed. In addition, the navigation aids investigated in the studies by McDonald and Stevenson were not representative of modern navigation aids, and none of the experimental studies described here evaluated learning from a constructivist perspective. The studies focussed on specific outcome measures of learning, rather than taking account of aspects of the learning process as a whole, such as the learners' engagement with the text and their feelings about learning with the electronic texts. Areas for further investigation were highlighted including examination of the effects of more recent developments in navigation aid technologies on learning from a constructivist perspective (i.e. assessing the whole learning process).

2.6 Chapter Summary

This chapter presented a review of literature and discussed issues related to navigation aids in educational electronic texts. This provides a background for the remainder of the research.

In section 2.2 constructivism was introduced as an epistemology that explains the way we learn. The review of literature on the different versions of constructivism and constructivist principles highlighted that there are many different ways in which constructivism has been described. As such, since this thesis takes a constructivist perspective the following research is needed here:

- ⇨ The synthesis of previous literature into a single version of constructivism which can be used to examine the implications of constructivism for navigation aids and learning.

In order to meet this need for a single version of constructivism, chapter 3 presents a framework of constructivism and navigation and the introduction to constructivism described in the present chapter forms a basis for this framework.

In section 2.3, electronic texts were put into context in a discussion of historical developments in e-Learning technology and categories of e-Learning technology. Electronic text was defined as text presented electronically with any type of linking/navigation structure. Navigation, and its meaning in electronic environments, was then discussed in section 2.4, with a particular focus on navigation in electronic texts. This was followed by a review of previous work on navigation aids and learning in section 2.5. Examples of recent developments in technologies to support navigation in educational environments were presented in section 2.5.1, and the experimental research discussed in section 2.5.2 showed that navigation aids affect the way that people use, and learn with, electronic texts. Since much of this experimental research focussed on non-interactive navigation aids or early hypertext or hypermedia systems, and focussed on learning in terms of outcome measures, this review highlighted two areas for further experimental investigation in this thesis:

- ⇨ Research into more recent developments in navigation technology.
- ⇨ Studies that investigate learning from a constructivist perspective and assess the whole learning process.

The next chapter sets out a framework of constructivism and navigation. This is used to generate hypotheses about types of navigation aids that might encourage constructivist learning with electronic texts. The literature reviewed in the present chapter contributes towards the selection of hypotheses generated under the framework.

3 A Framework of Constructivism and Navigation

This chapter presents a framework of constructivism and navigation. The framework is used to generate hypotheses for further investigation in this thesis.

3.1 Introduction

Constructivism is currently a popular theory in education. As discussed in chapter 2, previous research has examined the fundamental principles of constructivism. The aim of this research is to provide a rich insight into the effects of navigation aids on learning with educational electronic texts within the broad context of constructivism. As such, it is important to consider what constructivism means for navigation in educational electronic texts.

The core of the constructivist approach is that knowledge and meaning are not fixed, but rather are constructed through experience (Jonassen, 1994). However, as discussed in chapter 2, the extent to which constructivism forms a complete theory of learning and education has been questioned (Murphy, 1997). There have also been several different accounts of constructivism (e.g. constructivism or constructionism) and many different versions of the fundamental principles of constructivism (see chapter 2 for details). In this thesis constructivism is taken as an umbrella term (Squires, 1999) and as an epistemology that has implications for education. The fact that literature has offered different accounts of constructivism highlights a need for a single version of constructivism that consolidates previous constructivist literature to be used in this research. The aim of this framework is not to re-define constructivism, but rather to provide one viewpoint on constructivism and its implications for the employment of navigation aids in electronic texts.

Previous research has considered the implications of constructivism for e-Learning environments. For example, Papert (1980) used constructivist theories to develop an environment for the teaching of mathematics. Jonassen (1994; 1999), on the other hand, offered advice on how to design constructivist e-Learning environments. He proposed a model where a problem, question or project is the focus of the environment and various support systems surround it. Another approach was offered by Vrasidas (2000) who described a constructivist approach to the analysis and design of distance education courses via e-Learning as well as a means for evaluating learning. The work in this chapter extends this previous research and examines the implications of constructivism specifically for navigation aids in educational electronic texts. This framework synergises themes that have emerged in constructivist principles and literature into one detailed account of constructivism for use in this research. In the framework, the implications of these constructivist themes for navigation aids in educational electronic texts are considered and hypotheses about the effects of navigation aids on learning are developed.

The work in this chapter relates to objectives 1 and 2 outlined in chapter 1. To achieve **objective 1**, *"To define a detailed framework of the essential features of constructivism and its implications for navigation aids in educational electronic texts"*, this chapter presents the framework of constructivism and navigation. Following this, to achieve **objective 2**, *"To use this framework to formulate hypotheses about the effects of different navigation aids on learning with electronic texts"*, hypotheses are formulated from the framework and the justification for the selection of hypotheses is explained. The details of each of these hypotheses are then described.

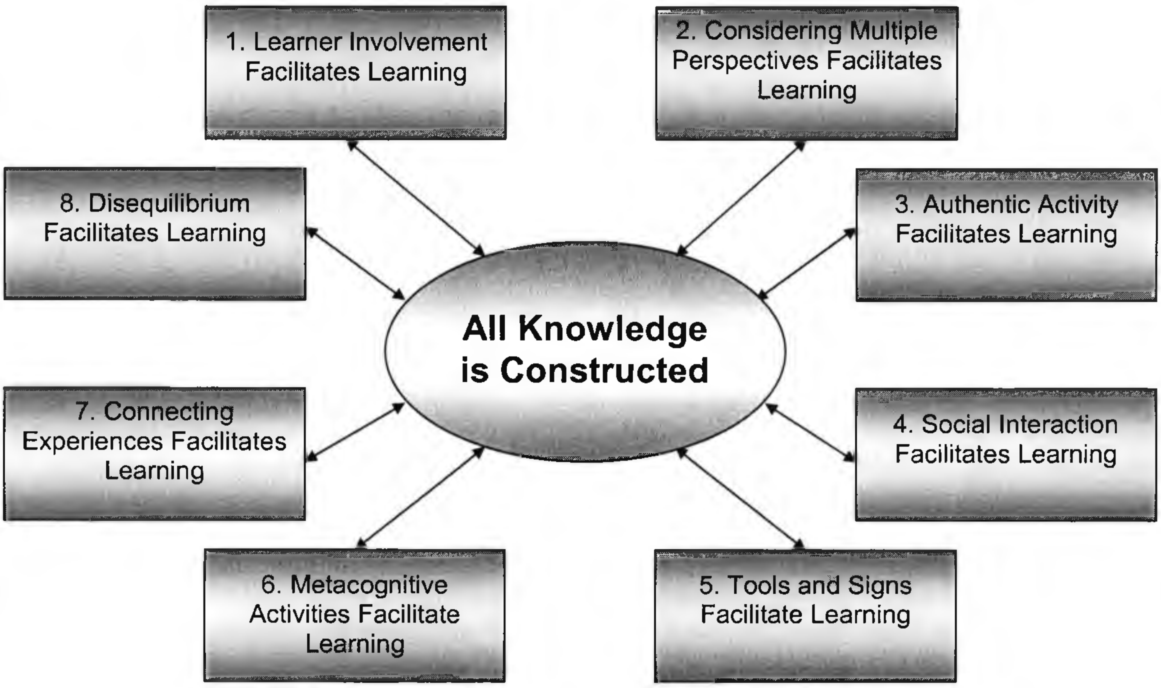

Figure 3.1. Themes in the framework of constructivism and navigation.

The framework breaks down constructivism into eight key themes, all related to a common central theme "All Knowledge is Constructed" (see figure 3.1). An overview of the framework and corresponding implications and hypotheses about navigation aids is given in table 3.1. Each theme is described in detail in this chapter and its relevance to navigation aids in educational electronic texts is discussed. Where relevant, implications for the design of navigation aids in educational electronic texts are identified and hypotheses about the effects on learning of particular types of navigation aids are framed. Finally this chapter describes how hypotheses are selected from the framework for further investigation in this thesis. Areas for further experimental investigation that were highlighted in the literature review in chapter 2 are used to motivate the selection of hypotheses.

Theme	Implications for Navigation Aids	Hypotheses
Central Theme: All Knowledge is Constructed	-	-
1. Learner Involvement Facilitates Learning	**1. a) i)** Navigation aids should offer the learner control to actively explore the electronic text so that they can actively learn with the electronic text.	**1. b) i)** Learners who use navigation aids that offer higher navigational freedom will show higher quality learning than learners who use navigation aids with lower navigational freedom.
2. Considering Multiple Perspectives Facilitates Learning	N/A.	N/A.
3. Authentic Activity Facilitates Learning	N/A.	N/A.
4. Social Interaction Facilitates Learning	**4. a) i)** Navigation aids should encourage learners to interact with others during navigation.	**4. b) i)** Learners who use navigation aids that offer interaction with others during navigation will show higher quality learning than learners who use navigation aids that do not offer interaction with others.
5. Tools and Signs Facilitate Learning	**5. a) i)** Navigation aids should be used as tools to aid the learner's development of new/alternative representations of electronic text content that would not have been possible with the text content alone.	**5 b) i)** Learners who use navigation aids that offer new/alternative representations of the text content (e.g. overviews of the electronic text content) will show higher quality learning than learners who use navigation aids that do not offer these representations.
	5. a) ii) Navigation aids should be used as an opportunity for learners to externally represent their ideas (e.g. through creating their own navigation aids).	**5 b) ii)** Learners who create their own navigation aids will show higher quality learning than learners who use existing navigation aids.
6. Metacognitive Activities Facilitate Learning	**6. a) i)** Navigation aids should encourage the learner to have metacognitive awareness of where they are in the learning process.	**6. b) i)** Learners who use navigation aids that show them where they have been and where they might go next will show higher quality learning than learners who use navigation aids that do not provide this information.
	6. a) ii) Navigation aids should encourage learners to plan their navigation.	**6. b) ii)** Learners who use navigation aids that support navigation planning will show higher quality learning than learners who use navigation aids that do not support navigation planning.
7. Connecting Experiences Facilitates Learning	**7. a) i)** Navigation aids should support the learner's access to prior knowledge, and allow the opportunity to elaborate, revise and reorganise information throughout learning.	**7. b) i)** Learners who use navigation aids that support access to previously visited information and allow the manipulation and reorganisation of that information will show higher quality learning than learners who use navigation aids that do not support this.
	7. a) ii) Navigation aids should support conceptual integration by showing connections across new information.	**7. b) ii)** Learners who use navigation aids that show connections across new information will show higher quality learning than learners who use navigation aids that do not show this.
8. Disequilibrium Facilitates Learning	N/A.	N/A.

Table 3.1. Overview of the framework of constructivism and navigation.

3.1.1 Central Theme: All Knowledge is Constructed

As discussed previously, the notion that all knowledge is constructed is central to a constructivist approach (e.g. Knuth and Cunningham, 1993; Duffy and Cunningham, 1996; von Glasserfeld, 1996). As such, it can be assumed that higher quality learning is associated with more elaborate knowledge constructions, and learning can be seen as an active process of constructing knowledge rather than acquiring it (Simons, 1993; Dunlap and Grabinger, 1996). For the purposes of this thesis, because they overlap in their underlying meaning, the following constructivist concepts have been grouped into this central theme: active learning, deep processing, cognitive engagement, discovery learning and reflection. These issues are connected to each and every theme in the framework.

3.1.1.1. Active Learning, Deep Processing and Cognitive Engagement

Knowledge construction relies on active learning (Jonassen et al. 1993) where learners perform more complex mental operations (Eysenck and Keane, 1995). This might be by fitting new ideas with existing knowledge or adjusting existing knowledge to accommodate new ideas. Concepts that relate to active learning include deep "levels of processing" and "cognitive engagement". In terms of different levels of mental processing of information, deeper processing is associated with situations where a learner is encouraged to create their own meaning and understanding of information, rather than, for example, memorising set information. Furthermore, it has been shown experimentally that deeper levels of processing of stimuli lead to more elaborate, longer lasting, and stronger memory traces for those stimuli (Craik and Lockhart, 1972). A similar constructivist proposition is that learners should be encouraged to think within a domain (Duffy and Cunningham, 1996), since this represents one means of encouraging learners to use deeper processing. Thinking within a domain, for example by evaluating understandings, judging relevance and making decisions, is the essence of active learning (Duffy and Cunningham, 1996).

Cognitive engagement is also related to active learning. Literature on "cognitive engagement" has been somewhat elusive about the actual definition of the term. Richardson and Newby (2004) define it in terms of learners' motivations and strategies. However, since this concentrates more on conative, rather than cognitive, aspects of engagement it does not seem appropriate here. Investigations of cognitive engagement have concentrated on the cognitive aspects of engagement in terms of higher order thinking and cognitive learning strategies (e.g. McLoughlin and Luca, 2000; Stoney and Oliver, 1999; Greene and Miller, 1996). Hence, in this thesis "cognitive engagement" is equated to higher order thinking where learners engage in complex mental activities as they construct knowledge.

McLoughlin and Luca (2000) used a five phase model to analyse cognitive engagement in discussion board interactions. The model categorised stages of knowledge construction, from knowledge sharing to knowledge building. Although they did not directly define cognitive engagement, they defined "higher order thinking" as the learners' capacity to go beyond the information given, to critique and evaluate information, and to have metacognitive and problem solving abilities. This is similar to the original account of cognitive engagement given by Corno and Mandinach (1983) who claim that the highest form of cognitive engagement is self-regulated learning. Corno and Mandinach assert that self-regulated learning involves the following activities:

- Alertness
- Selectivity
- Connecting experiences
- Planning
- Monitoring

Stoney and Oliver (1999), on the other hand, explored students' cognitive engagement with a multimedia microworld by analysing the students' discourse as they used the microworld. Again, they did not directly define cognitive engagement, but they looked for evidence of higher and lower order thinking to investigate cognitive engagement. In their coding scheme evidence of higher order thinking included:

- Planning/strategy
- Uncertainty
- Predicting/imposing meaning
- Multiple perspectives
- Coaching activities

Evidence of lower order thinking was related to the following operational tasks:

- Procedural activities
- Browsing
- Information seeking activities

Another approach was taken by Greene and Miller (1996). Again, similar to Corno and Mandinach (1983) they define cognitive engagement as self-regulation and deep strategy use and measured these activities through students self-reports on a questionnaire. For example, students were asked to rate their agreement with the statement "When I read for this exam I stopped to ask myself whether or not I am understanding the material". They also compared this to learning goals and learning achievement. They found that cognitive engagement has benefits in terms of learning achievement in that it suppresses the negative effects of shallow processing, or low cognitive engagement.

In sum, active learning involves deep processing of information to be learned and cognitive engagement. The themes in this framework of constructivism and navigation suggest means of facilitating active learning.

3.1.1.2. Discovery Learning

Discovery learning is an instructional technique that may be employed to facilitate the active construction of knowledge. It is an approach to learning that requires learners to be active and inventive as they develop and test their own questions and hypotheses (Duffy and Cunningham, 1996). Other approaches that are similar include learning by doing, exploratory learning, inquiry based learning, experiential learning and problem based learning (see Duffy and Orrill, 2003). Discovery-based approaches that involve the invention of new understandings are an archetype of active learning techniques and encompass concepts from every theme in this framework.

3.1.1.3. Reflection in Learning

Learning has been described as a reflective activity (Simons, 1993), and reflective abstraction has been claimed to be the driving force of learning (Fosnot, 1996). Reflection has been assigned many definitions, not all of them congruent (see Boud et al. 1985a, for a discussion). In these definitions, reflection is described as a response to experience, where the goal of reconstructing experience is central (Boud et al. 1985a). It is a generic term for intellectual and affective activities that allow learners to explore experiences and to develop new understandings and appreciations (Boud et al. 1985b). Constructivists propose that reflective activities facilitate the development of knowledge (e.g. Cunningham, Duffy et al. 1993; Duffy and Cunningham, 1996; Knuth and Cunningham, 1993). Similarly, writings about reflection suggest that education should be constructivist (e.g. Boud et al. 1985a; Boud et al. 1985b). The importance of the role of reflection in crystallising and reinforcing previous learning, developing concepts and making generalisations was also highlighted by Boud et al. (1985a).

There have been differing accounts as to whether reflection occurs after activities/experiences (Boud et al. 1985a; Boud et al. 1985b) or whether it can occur during activity (Schön, 1983). There are also issues about the use of the term "reflection" and how its meaning differs from "metacognition". "Metacognition" has been defined as "the awareness individuals have of their own thinking and the evaluation and regulation of their own thinking" (Wilson, 2000). For example, Schön's (1983) model of reflection during activity appears to relate to ideas commonly associated with definitions of metacognition since it concentrates on how people think about their own thoughts and actions (see Theme 6: Metacognitive Activities Facilitate Learning, for more on metacognition).

In sum, reflection is a broad term that has been used to embrace both metacognitive and cognitive activity, and generally refers to purposeful thought. Since the term is conceived in so many ways its usefulness is reduced (Wilson, 2000). As such, only metacognitive activities are specifically referred to as a theme in this framework (see theme 6), reflection on the other hand is thought to be something that is related to all themes in the framework.

3.1.2 Theme 1: Learner Involvement Facilitates Learning

Theme 1, Learner Involvement Facilitates Learning, encompasses the idea suggested by Cunningham et al. (1993) that students should assume responsibility for asking questions in their learning, rather than just reproducing information. In this thesis, it is proposed that three issues relate to this theme: learner control, motivation and ownership. These three issues are highly interconnected and each of these constituent parts of learner involvement affect how active a learner will be in developing their knowledge constructions.

Definitions of learner control, motivation and ownership and related issues are given in turn, and the relationship between them is described. Finally, at the end of this section, the relevance of these issues to navigation aids is considered and implications and hypotheses about navigation aids and learning are discussed.

3.1.2.1. Learner Control

In the context of e-Learning, control is about the ability to exercise choice and make decisions when using e-Learning technology. Control can be viewed as a spectrum from learner control to program control (see figure 3.2). In e-Learning, control has been referred to as the freedom the learner or technology has to take command over the display, selection and sequencing of content (Merrill, 1975 cited in Leung, 2003).

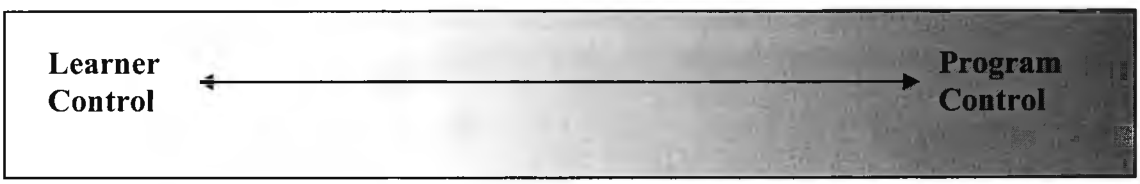

Figure 3.2. The control spectrum.

Learner control is about the degree to which a learner can direct their own learning process by controlling one or more variables in an e-Learning environment. There are several variables that can be controlled including choice of content, sequencing, pace, difficulty, number of opportunities to practice concepts, learning review and rehearsal, advisement strategy and feedback (Leung, 2003; Dillon and Gabbard, 1998). High levels of learner control occur when the learner is able to control these variables, and exercise choice and make decisions in their learning. On the other hand, high levels of program control occur when the educational technology controls these variables, thereby giving less control to the learner (Hannafin and Sullivan, 1995; Shyu and Brown, 1992; both cited in Leung, 2003). A related issue is the notion of the learner's feelings of control. Even if control is offered to the learner, they may not necessarily feel or recognise this control. For example, a learner may be offered the control to choose which topic they are going to learn about first in an e-Learning course. However, if they are new to the information in the course, being given this choice might not actually make them feel more in control of their learning. They may be indifferent about their level of control over their learning, or if they are presented with choices that are too difficult for them, because they are unfamiliar with the learning material, it may actually result in them feeling less in control of their learning.

Educationalists have argued for some time that providing appropriate levels of learner control can increase the development of knowledge (Eveland and Dunwoody 2001), and many authors have claimed that the capability of digital technology to enhance learner control over the pace and detail of information delivery has a positive effect on learning (Dryden, 1994; Landow, 1992; Landow and Delany, 1991, all cited in Dillon and Gabbard, 1998). However, the results of studies that have examined the effects of high levels of learner control are mixed as to whether it really is beneficial. It has been suggested that the apparent potential of learner control in improving learning has never been experimentally established (Goforth, 1994 in Duffy and Cunningham, 1996). Bell and Kozlowshi (2002) even argue that the most consistent finding in research has been that learners do not make good instructional use of the control they are given. Moreover, Duffy and Cunningham (1996) suggest that learner control is the epitome of an objectivist view of learning since it often appears to be simply related to the processing of variables and the inputting of information.

Nevertheless, many supporters of a constructivist approach advocate that learners should be given some control over their learning (Honebein et al. 1993; Simons, 1993; Duffy and Cunningham, 1996), and it is hard to see that a learner can truly be active with a very low level of control. Therefore, it is assumed here that in order for a learner to be active and involved, they need to have some level of control over their learning.

3.1.2.2. Motivation in Learning

Pinrich and Schunk (1996) described motivation as the process whereby goal-directed activity is instigated and sustained. It is a process rather than a product and involves goals that provide impetus and direction for action. Motivation can influence what, when and how we learn (Schunk, 1991). Motivated learners engage in activities they believe that will help them learn, for example by taking good notes, checking their own understanding or asking for help. Motivation influences learning, and learning performance influences motivation in a cyclical manner. Tasks where the learner has control are said to be intrinsically motivating (Bruner, 1960). In this thesis, it is suggested that involved learners will be motivated learners.

3.1.2.3. Ownership in Learning

It is proposed here that involved learners will also feel high levels of ownership for their learning. Learner ownership is promoted as illustrating the student-centredness of constructivist learning (Honebein, 1996) and has been proposed to be important in terms of motivation to learn (Biggs, 1999). According to O'Neill and Barton (2004), there is consensus in research that learner ownership leads to more active participation and engagement in the learning process. Similarly, Gross (1997) reported that attempts to encourage ownership in a classroom setting had positive effects on learning. By encouraging student input, students came to feel responsible for their learning and in turn it was found that they grasped material more firmly, exhibited higher levels of inquiry and pursued tasks independently. Furthermore, Cresp (2002) found that giving students the opportunity to take control and assume ownership of their learning improved their attitudes towards their learning.

Milner-Bolotin's (2001) definition of ownership is employed in this research. In this definition, learner ownership is broken down into three interacting components of the learning process: finding personal value, feeling in control, and taking responsibility (see figure 3.3). Finding personal value is about understanding how the knowledge and skills developed during learning might be useful in situations outside the original learning environment. Feeling in control occurs when the learner feels able to make decisions and to be a proactive rather than reactive learner. Responsibility in learning, on the other hand, refers to the learner feeling responsibility, or feeling accountable, for the process of learning as well as the results of learning. The highest levels of ownership occur when all three components overlap. Situations where only one or two components overlap result in lower feelings of overall ownership.

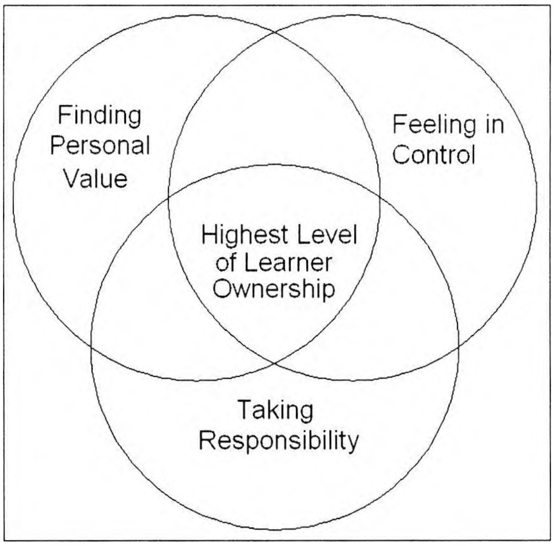

Figure 3.3. Learner ownership as an interactional effect of feelings of personal value, control and responsibility. Adapted from Milner-Bolotin (2001).

3.1.2.4. Relationship Between Learner Control, Motivation and Ownership

Learner control, motivation and ownership are all inter-connected. The extent of learner control is the component that can be manipulated in the e-Learning environment. Motivation and ownership are resultant feelings or behaviours. They may influence each other, and can be influenced by learner control (Becker and Dwyer, 1994; Milner-Bolotin, 2001), amongst other factors. The relationship between learner control and ownership is highlighted by Wright and Wright (1998) (cited in O'Neill and Barton, 2004) who proposed that giving students control over their learning should affect ownership because the students discover ideas themselves. Milner-Bolotin (2001) proposes that learning environments that allow learners higher control over their learning, allow them to choose topics of investigation which are more relevant for them, and allow them to be more responsible for their learning, provide more opportunities for learners to develop a sense of ownership. Similarly, in an experimental study, Becker and Dwyer (1994) found that higher learner control led to higher learner motivation.

In sum, learner involvement is about encouraging the development of elaborate knowledge constructions by motivating learners and encouraging them to feel high levels of ownership for their learning. One means of doing this is by offering learners an appropriate level of learner control.

3.1.2.5. Relevance to Navigation Aids in Electronic Texts

Previous experimental research has examined the effects of control over navigation on learning. This highlights the fact that the learner control aspect of learner involvement is particularly relevant to navigation aids. For example, in one study (Neiderhauser et al. 2000), the intensive use of cross-referential embedded links in hypertext, i.e. when the learner is making use of the control offered to them, was found to be negatively correlated with learning. In another study, McGrath (1992) hypothesised that the increased learner control offered by hypermedia and menu driven pages would positively affect learning as compared to linear electronic text with paging buttons, and paper based materials. However, no significant differences between conditions were found, implying that the different levels of control offered by these conditions had little effect on learning. Nevertheless, Becker and Dwyer (1994) found that learner control over navigation offered some benefits for learning. They studied the effects of an electronic text with embedded links and a non-interactive map, which they argued offered higher levels of learner control, compared to the same text presented on paper. Their findings revealed that learners who used the electronic text reported higher feelings of control and higher levels of intrinsic motivation for their learning than learners who simply read the paper-based text.

The differences in these findings may have arisen due to variations in the systems used (e.g. content subject matter, overall design and usability), types of experimental tasks, and interpretations of learner control in electronic texts (i.e. how learner control was realised in the experiments). In addition, this research has generally focused on differences between hypertext (with embedded links) and linear text (with paging buttons). In contrast, little attention has been given to aggregate navigation aids that can offer access to every page in the electronic text at any one time.

Due to the proposed benefits of learner control discussed earlier, the following implication for navigation aids in educational electronic texts is given here:

1. a) i) Navigation aids should offer the learner control to actively explore the electronic text so that they can actively learn with the electronic text.

This thesis research focuses on one interpretation of learner control in electronic texts: navigational freedom. "Navigational freedom" refers to the degree of choice a learner has when deciding which page to visit. This equates to the number of different destination links a learner has to choose between on any one page of the text and the type of navigation aid(s) employed determines the level of navigational freedom offered. Examples of navigation aids with different levels of navigational freedom are shown in table 3.2.

Level of Navigational Freedom	Navigation Aid	Explanation
Lower	Paging Buttons ("Previous" and "Next" Buttons)	The learner only has the choice of going to the previous or next page in a predefined sequence.
	Home Button	The learner only has the choice to return to the home page.
	Back/Forward Buttons (e.g. on a browser)	The learner only has the choice of going back or forward in a web cache stack.
Medium	Embedded Links	It is often the case that a number of embedded links appear on a page at any one time and give the learner the choice of selecting between these links. However, the links rarely represent every page in an electronic text, so they do not give this higher level of choice.
	Localised Menus/Maps or Contents Lists	These depict a localised section of an electronic text and give the learner the choice of visiting any page within that section. However, since they do not represent every page in the electronic text, they do not allow the learner to choose between every page.
Higher	Maps, Contents Lists or A-Z Indices that Show All the Pages in an Electronic Text	The learner is able to choose between every page in the electronic text from the map/contents list/A-Z index.
	A *Complete* History List that Shows All the Pages in an Electronic Text	The learner is able to choose between every page in the electronic text from the history list.

Table 3.2. Examples of navigation aids with different levels of navigational freedom.

The following hypothesis about the effects of the level of navigational freedom offered by navigation aids is framed here:

1. b) i) Learners who use navigation aids that offer higher navigational freedom will show higher quality learning than learners who use navigation aids with lower navigational freedom.

3.1.3 Theme 2:Considering Multiple Perspectives Facilitates Learning

Since constructivists believe that there is no single set reality which we all perceive, they propose that there are many possible worldviews and perspectives (Knuth and Cunningham, 1993; Duffy and Cunningham, 1996). The consideration of these different perspectives encourages the development of more elaborate knowledge constructions. Dunlap and Grabinger (1996) claim that when successful learners work on problems they constantly refine their decisions in order to come up with more effective and efficient strategies, approaches and solutions to these problems. They consider multiple perspectives. Less successful learners tend to stop at one pass through information and only examine one viewpoint.

In terms of education, several authors endorse the benefits of encouraging learners to experience and appreciate multiple perspectives (e.g. Honebein, Duffy et al. 1993; Cunningham, Duffy et al. 1993; Honebein, 1996). Spiro and Jehng (1990) and Dunlap and Grabinger (1996) suggest that instructors should encourage learners to revisit concepts, information, and problems by considering how they can be solved or applied in a number of different situations from a variety of perspectives.

Two further educational considerations arise from this theme. Firstly, instructors should be aware that learners may perceive their educational environment in a very different way to the way that they do themselves (von Glasserfeld, 1996). Secondly, another issue is the way that instructors should deal with errors, or misunderstandings. Fosnot, (1996) suggested that misunderstandings should not be avoided, but rather they should be taken as an opportunity for discussion; using multiple perspectives is one way of dealing with these misunderstandings.

3.1.3.1. Relevance to Navigation Aids in Electronic Texts

This theme concerns the educational material which is presented to learners and whether this material is a single account of the information to be learned, or whether learners are encouraged to consider the information from multiple perspectives. However, these issues do not appear to have any obvious relevance to navigation aids in educational electronic texts.

Although the navigation aid can determine the way that learners access multiple perspectives on educational material, whether these multiple perspectives are included in the educational material is an issue for the design of a course as a whole. For example, paging buttons could allow learners to view multiple perspectives in a linear sequence. In contrast, a contents list may allow the learner to choose the order in which they access these multiple perspectives. Nevertheless, both types of navigation aids could also be used to present content that does not include multiple perspectives. Therefore, the design of the navigation aid is independent of whether the course design includes multiple perspectives on the educational material. As such, no implications or hypotheses about the use of navigation aids in educational electronic texts are identified from this theme.

3.1.4 Theme 3: Authentic Activity Facilitates Learning

Knowledge is dependent upon the context in which it is developed and the context in which it is recalled (Duffy and Cunningham, 1996; Simons, 1993; Godden and Baddeley, 1975). In relation to this, constructivists claim that knowledge *is* effective action (Knuth and Cunningham, 1993) and that knowledge is always situated within certain contexts. In other words, there is no distinction between knowing and doing because knowledge is only apparent when it is used. Similarly, Honebein et al. (1993)

indicated the importance of action in the development of knowledge. They claimed that knowledge develops through action because understanding is embedded in experience. This has implications for the way that knowledge develops and the way that knowledge should be assessed.

Jonassen (1994) suggested that instructors should provide learners with authentic tasks to enable context dependent knowledge construction. Authentic tasks are those that reflect the real world and real world problems. Learning should be embedded in environments that involve these realistic and relevant tasks (Duffy and Cunningham, 1996), and should be grounded in the noise and complexity of the real world (Cunningham et al. 1993; Jonassen, 1994). These complex learning environments apply best to advanced knowledge acquisition in ill-structured domains (Honebein et al. 1993). Learning should also be case-based rather than through predetermined instructional sequences (Jonassen et al. 1993), and case-based learning can be achieved by engaging learners in project based work. In addition, apprenticeship, where the learner develops knowledge and skills in real-world tasks, is important to this type of learning (Honebein et al. 1993).

3.1.4.1. Relevance to Navigation Aids in Electronic Texts

This theme is about grounding educational material in real world contexts. For example, learners might find out about designing a website by engaging in a real task where they are required to design a website for a real client organisation. In e-Learning environments this theme may have relevance when determining the overall metaphor for the environment. The overall metaphor determines the types of tasks that learners engage in and the way that learners think about and interact with the e-Learning environment as a whole. For example, the Open University used the overall metaphor of a software house for a VR e-Learning environment on CD-ROM called the Open Software Solutions Multimedia Environment (Hall et al., 2000). This environment was designed to teach software engineering.

However, navigation aids are just one part of an e-Learning environment. Navigation aids may mirror the physical world by employing metaphors in their appearance and the way they should be used. For example, the navigation aids in an online library may be represented as tabs, similar to those in a paper-based catalogue. Yet, the issues in this theme are at a higher level than just one aspect of the learning environment. They are concerned with the types of tasks learners engage in and how authentic their learning environment is as a whole. This theme is more relevant for overall course design, or the design of the whole educational environment, rather than having any obvious relevance for navigation aids in particular.

3.1.5 Theme 4: Social Interaction Facilitates Learning

Knowledge develops in social and cultural contexts (Duffy and Cunningham, 1996). Learning is not the lonely act of an individual, even when it is undertaken alone (Duffy and Cunningham, 1996), and many authors promote the role of social interactions and dialogue in knowledge development (e.g. Knuth and Cunningham, 1993; Honebein, 1996; Simons, 1993; Duffy and Cunningham, 1996). Duffy and Cunningham (1996) argue that learning is an inherently social-dialogical activity, based on interaction and discussion between learners where the learners are distributed, multidimensional participants in a socio-cultural process. According to Fosnot (1996) this dialogue within a community engenders further thinking. The emphasis on social interaction in constructivism leads constructivists to argue that co-operative learning, collaborative learning, and co-operative problem solving all facilitate the development of knowledge (Dunlap and Grabinger, 1996; Honebein et al. 1993).

Supporters of constructivism also argue that learning activities should require interaction with others in a process of social negotiation, where learners argue and debate with others during their learning (Jonassen et al. 1993; Jonassen 1994; Duffy and Orrill, 2003). Social negotiation is important because it also contributes to the individual's ability to internally negotiate meaning (Vygotsky, 1978 in Duffy and Cunningham, 1996; Fosnot, 1996). For example, the activity of defending and proving ideas within a classroom community is important (Fosnot, 1996). Furthermore, as Honebein (1996) points out, learning should reflect collaboration between instructors and learners, as well as between learners and their peers. Interaction with an instructor, expert, or more advanced peer will lead to the learner performing at a higher level (Duffy and Cunningham, 1996), and this increase in performance is known as the zone of proximal development (ZPD) (e.g. Vygotsky, 1978). Support for learning in the ZPD, otherwise known as scaffolding, should support the growth of a learner in general, rather than teaching them towards some well defined end (Duffy and Cunningham, 1996). In fact, Duffy and Cunningham (1996) also reason that the environment or culture in the learning environment may provide scaffolding as well as instructors or more advanced peers.

3.1.4.1. Relevance to Navigation Aids in Electronic Texts

This social interaction theme has particular relevance for navigation in educational electronic texts as demonstrated by the considerable interest in a social navigation approach to the design of information spaces (e.g. Dourish and Chalmers, 1994; Munro et al. 1999; Höök et al. 2003). This is reflected in attempts to capture aspects of social interaction in the design of navigation aids in educational environments (e.g. Dron et al. 2001, CoFIND; Maly et al. 2001, CoBrowser; Zeiliger et al., 1999 and Esnault et al. 2004, Nestor Navigator).

In summary, due to the fact that constructivism advocates social interaction in learning, the following implication for navigation aids in educational electronic texts can be identified:

4. a) i) Navigation aids should encourage learners to interact with others during navigation.

Based on this, the following hypothesis about the effects of navigation aids that offer social interaction can be framed:

4. b) i) Learners who use navigation aids that offer interaction with others during navigation will show higher quality learning than learners who use navigation aids that do not offer interaction with others.

3.1.6 Theme 5: Tools and Signs Facilitate Learning

The use of tools and signs affects the way we think and learn and the development of knowledge is mediated by two means: tools (technical tools) and signs (semiotic tools) (Duffy and Cunningham, 1996). Examples of tools are a hammer, or a key board. In contrast, language is an example of a sign, or semiotic tool. Symbols used in an interface, such as icons, are also examples of signs, or semiotic tools. The use of these tools and signs can affect both physical and mental activity (Knuth and Cunningham, 1993).

The concept of tool mediation is closely associated with Activity Theory, a leading theoretical approach in Russian constructivist psychology (Kaptelinin, 1993). There are two key principles of Activity Theory:

- Tools and signs mediate the nature of human activity and, when internalised, influence human mental development (Jonassen and Rohrer-Murphy, 1999).
- The internalisation/externalisation principle.

These principles are consistent with constructivism, situated learning, distributed cognition, social cognition and case-based reasoning. Although these principles overlap to some extent they will be discussed in turn. The first principle has implications for high quality learning and suggests that learners should be provided with multiple representations of reality (Jonassen, 1994) and should use multiple modes of mental representation (Cunningham, et al. 1993; Honebein, 1996), so that their understandings are not limited by a single representation. This concept is related to the ideas in theme 2, on multiple perspectives. However, it is distinct since it concerns the tools and signs which are used to represent information, rather than the information conveyed by these tools. In terms of technology, one recommendation might be to choose technologies that aid the learner's development of new representations that would not otherwise have been possible, and the different representations should be exploited in terms of what they can contribute to knowledge construction (Knuth and Cunningham, 1993).

The second principle of Activity Theory is the internalisation/externalisation principle. Internalisation is the process of transforming tools and signs, external actions, and social relations into internal psychological functions. Externalisation, on the other hand, occurs when mental processes manifest themselves in an individual's external actions (Zeiliger, 1998). It is the articulation of internal mental processes, and this articulation occurs through tools and signs. Articulation has been shown to contribute to the development of new knowledge (Koschmann and LeBaron, 2002) both through summarization (Davis and Hult, 1997; King, 1992) and self-explanation (Aleven and Koedinger, 2002). For example, Davis and Hult (1997) found that students who created summaries during a lecture scored significantly higher than those who did not on a free-recall question immediately after the lecture, and on a test twelve days later. King (1992) produced similar findings. He found that students who wrote summaries of a lecture recalled more of the lecture content at immediate testing than students who simply reviewed their lecture notes. Likewise, articulation during problem solving has been found to enhance learning. Aleven and Koedinger (2002) found that students who explained their steps during problem solving with a computer-based tutor achieved greater understanding than students who did not explain their steps. Overall, these findings highlight articulation as a beneficial activity in learning.

3.1.6.1. Relevance to Navigation Aids in Electronic Texts

The tool mediation principle of activity theory, and the suggestion that technologies should encourage the development of new representations or views, both have relevance for navigation aids in educational electronic texts. Some navigation aids, such as contents lists and navigation maps, provide overviews of the information contained in electronic texts, and therefore give an alternative representation to that contained purely in the text content. As such, the following implication for the design of navigation aids can be given:

5. a) i) Navigation aids should be used as tools to aid the learner's development of new/alternative representations of electronic text content that would not have been possible with the text content alone.

Accordingly, the following hypothesis can also be made:

5 b) i) Learners who use navigation aids that offer new/alternative representations of the text content (e.g. overviews of the electronic text content) will show higher quality learning than learners who use navigation aids that do not offer these representations.

However, the type of overview or representation of the content in the navigation aid may have different levels of educational utility. Previous research discussed in chapter 2 showed that there have been mixed findings for experimental studies on the effects of aggregate navigation aids that give an overview of the electronic text content. Some studies showed that graphical map overviews were beneficial to learning (e.g. McDonald and Stevenson, 1999; Dee-Lucas and Larkin, 1995); whereas other studies showed that graphical map overviews had little or negative effects on learning (e.g. Wenger and Payne, 1994; Stanton et al., 1992).

The issue of using multiple forms of representation (e.g. text, graphics, video) for the presentation of content seems to be less relevant to navigation aids, as it focuses on the different forms of media used to present educational material to learners. Although the navigation aid may present information in a different form to that in the text content, the use of multiple media is not an issue for the navigation aid itself as it is not expected to present multiple forms of media. It is an issue for the content material.

On the other hand, the internalisation/externalisation principle of activity theory, and the implication that the articulation of knowledge is beneficial to knowledge development, is relevant for navigation in electronic texts. As well as navigation aids being static unchangeable objects on the interface which learners use in order to navigate, dynamic navigation aids offer learners the ability to change and update the aid as they navigate. These changes may be controlled by the learner, allowing them to articulate their ideas as they create their own navigation aids.

Recent developments in navigation have resulted in navigation aids that may be created by the user while interacting in an electronic environment. For example, as discussed in chapter 2, Nestor Navigator (e.g. Zeiliger et al., 1999) is a web browser add-on that creates a graphical trace of visited web pages as the learner navigates.

Learners can rearrange and edit these traces, thus creating their own navigable structures such as graphical maps, contents lists, and alphabetical indices, which they can use as navigation aids. Learners can create the navigation aid and articulate their ideas about the electronic text content. Accordingly, the following implication for the design of navigation aids in educational electronic texts can be identified:

5. a) ii) Navigation aids should be used as an opportunity for learners to externally represent/articulate their ideas (e.g. through creating their own navigation aids).

Based on this, the following hypothesis can also be framed:

5 b) ii) Learners who create their own navigation aids will show higher quality learning than learners who use existing navigation aids.

3.1.7 Theme 6: Metacognitive Activities Facilitate Learning

This theme reflects the focus in constructivism on "higher level" skills and knowledge as demonstrated in Knuth and Cunningham (1993)'s claim that knowing how we know, or metacognition, is the ultimate human accomplishment. As mentioned earlier under the central theme of this framework (see section 3.1.1), metacognition has been defined as "knowledge and cognition about cognitive phenomenon" (Flavell, 1979), or in other words, "...the awareness individuals have of their own thinking and the evaluation and regulation of their own thinking" (Wilson, 2000). Wilson's (2000) definition has three aspects: awareness, evaluation and regulation. According to this model, metacognitive awareness is an individual's awareness of their stage in the learning process, their content knowledge, their personal learning strategies and their knowledge of what needs to be done, what has been done and what might be done in certain problem solving situations. Metacognitive evaluation, on the other hand, refers to judgements made about one's own thinking processes, capacities and limitations as these are used in particular learning situations, or as self-attributes. The final part of this definition, metacognitive regulation, happens when individuals make use of their metacognitive skills (such as planning, self-correcting and goal setting) to control their knowledge and thinking.

In terms of learning, metacognitive activity is associated with successful learners (Dunlap and Grabinger, 1996). It has been shown to lead to higher performance on skill acquisition and transfer (Forrest-Pressley et al. 1985). Metacognitive activity is therefore seen as beneficial to learning, implying that metacognitive awareness, evaluation and regulation should be encouraged (Dunlap and Grabinger, 1996).

3.1.7.1. Relevance to Navigation Aids in Electronic Texts

The implication that learners should be encouraged to be metacognitively aware may have relevance to navigation aids. The navigation aid can provide an opportunity to help learners be aware of what they have already done (e.g. what information they have already accessed in an electronic text) and what they still have to do. The Interactive History List discussed in chapter 2 is an example of an application that utilizes this idea. It encourages learners to be aware of information they have already navigated, as well as encouraging them to reflect upon their reasons for visiting information (e.g. Kashihara et al. 2001). Since metacognitive awareness has been proposed to have benefits for learning (Dunlap and Grabinger, 1996), the following implication for the design of navigation aids in educational electronic texts can be drawn:

6. a) i) Navigation aids should encourage the learner to have metacognitive awareness of where they are in the learning process.

Accordingly, the following hypothesis can also be framed:

6. b) i) Learners who use navigation aids that show them where they have been and where they might go next will show higher quality learning than learners who use navigation aids that do not provide this information.

The suggestion that learners should be encouraged to use metacognitive regulation also appears to be relevant to navigation aids. Different navigation aids may give different levels of support for learners as they set goals and plan what they are going to do next. This is particularly relevant for navigation planning. The Navigation Path Planning Assistant, also discussed in chapter 2, is an example of navigation support that encourages planning activities (e.g. Suzuki et al. 2001). This tool allows learners to plan their navigation before they visit pages in an electronic text. Since Wilson (2000) proposes that there are benefits to metacognitive regulation through planning, the following implication for the design of navigation aids in educational electronic texts can be identified:

6. a) ii) Navigation aids should encourage learners to plan their navigation.

Following from this implication it can also be hypothesised:

6. b) ii) Learners who use navigation aids that support navigation planning will show higher quality learning than learners who use navigation aids that do not support navigation planning.

In contrast, encouraging the use of metacognitive evaluation is not considered to be of particular relevance to navigation aids. The evaluation of learning strategies, or even navigation strategies, for example, is considered beyond the role of a navigation aid. In terms of navigation strategies, a navigation aid may be able to bring the navigation to the attention of the learner (metacognitive awareness of the navigation strategy), but it seems unlikely that a navigation aid could encourage learners to actually evaluate their own strategies. It is the responsibility of the learner to judge whether their strategies are effective.

3.1.8 Theme 7: Connecting Experiences Facilitates Learning

Knowledge develops in a continuous process of construction that builds on existing knowledge structures, or what is already known (Dunlap and Grabinger, 1996; Simons, 1993). Through active learning, learners relate new information to prior knowledge (Jonassen et al. 1993) and connections across new experiences are sought. Since new knowledge is built upon existing knowledge, it is important that instructors account for the conceptual understandings that learners have at the time of learning (von Glasserfeld, 1996). Existing knowledge can then be used as a point of reference and as a foundation from which new knowledge structures are built (Dunlap and Grabinger, 1996). Learning activities should require learners to access prior knowledge and assemble more elaborate schemas from it (Jonassen et al. 1993). As learners progress, the undoing and reorganising of information is common and learners should be given the opportunity to do this (Fosnot, 1996).

For new experiences, Fosnot (1996) suggests that learners should consider connections across experiences. Boud et al (1985a) propose that concept maps are a useful tool for this activity, and it has been reported that concept maps aid learners' recall of more key ideas when they learn from a concept map than when they learn from text (O'Donnell et al., 2002).

3.1.8.1. Relevance to Navigation Aids in Educational Electronic Texts

The suggestion that learners should be given the opportunity to access prior knowledge and to reorganise this knowledge is relevant to navigation in educational electronic texts. Navigation aids that provide a history of where the user has already been in an electronic text can be seen to represent an external record of prior knowledge that a learner may be expected to have. Furthermore, navigation aids that allow the learner to edit and reorganise this history may also be seen to support the learner in building upon and reorganising prior knowledge. The Interactive History List (Kashihara et al. 2001) is an example of such a navigation aid. In addition, Nestor Navigator also supports this since it creates a navigational trace of pages the learner has visited which can be rearranged and edited allowing the learner to create their own navigation aid. Based on the constructivist propositions that accessing and building on prior knowledge are advantageous, the following implication for the design of navigation aids in educational electronic texts can be identified:

7. a) i) Navigation aids should support the learner's access to prior knowledge, and allow the opportunity to elaborate, revise and reorganise information throughout learning.

Consequently, the following hypothesis can be framed:

7. b) i) Learners who use navigation aids that support access to previously visited information and allow the manipulation and reorganisation of that information will show higher quality learning than learners who use navigation aids that do not support this.

The suggestion that learners should consider connections across experiences is also relevant to navigation aids. Navigation aids can be used to represent connections across information navigated. As highlighted above, concept maps have been proposed to be a useful tool for this activity (Boud et al., 1985a). In fact, as discussed in chapter 2, some studies have found that map navigation aids that show the conceptual structure of the electronic texts encourage the development of a more durable understanding of electronic text content than either a map that shows the link structure of the text or plain hypertext (McDonald and Stevenson, 1999). Based on the proposed benefits of concept maps, the following implication for the design of navigation aids in educational electronic texts can be identified:

7. a) ii) Navigation aids should support conceptual integration by showing connections across new information.

Following from this, it can also be hypothesised:

7. b) ii) Learners who use navigation aids that show connections across new information will show higher quality learning than learners who use navigation aids that do not show this.

3.1.9 Theme 8: Disequilibrium Facilitates Learning

According to the Piagetian theories of knowledge construction, the mechanism for the development of knowledge is "equilibration" (Brown, 1995). When an individual begins to develop an understanding, or internal representation, of an experience or concept, they develop a relatively stable and balanced internal representation. They are said to have reached a state of equilibrium. This means that their internal representations and understanding of their environment, and the stimuli it contains, are in balance. However, because of the complexity of our environment no internal representation is likely to incorporate all of the influential variables (Brown, 1995) and there will be some situations where internal representations are inadequate to some extent. The pattern of understanding may become destabilised leading to a state of uncertainty or disequilibrium.

In this situation, the internal representation has to be adapted. This consists of two complementary processes: assimilation and accommodation. Assimilation occurs when new experiences are added to the store of knowledge. However, learning is rarely a matter of simple assimilation (Brown, 1995). Usually existing schemas have to be adjusted to incorporate new experiences and this process is known as accommodation.

Fosnot (1996) proposed that disequilibrium facilitates learning, since it encourages knowledge to be revised. As such, learners should be provided with challenging open-ended investigations that they can explore and use to generate new understandings. Fosnot (1996) also recommended that contradictions should be explored and discussed in order to induce disequilibrium and challenge the learners' thinking. In these situations learners will revise their existing knowledge.

3.1.9.1. Relevance to Navigation Aids in Educational Electronic Texts

The recommendations that learners should be provided with challenging investigations and instructors should highlight misunderstandings are both issues for instructors and the way that they design the educational environment and teaching strategies. Navigation aids can neither determine whether learning activities are challenging nor can they determine the way that counterexamples and contradictions are dealt with. As such, this theme leads to no obvious implications or hypotheses about the use of navigation aids in educational electronic texts.

3.1.10 Framework Summary

This section has presented a framework of constructivism and navigation. This provides a detailed version of constructivism for use in this research and a wide context for the development of hypotheses about the effects of navigation aids on learning. The framework consists of eight key themes in constructivist literature, and one central theme to which all other themes are related. Under each theme, consideration is given to the relevance of that theme for the design of navigation aids. Where appropriate, implications for the design of navigation aids in educational electronic texts are given and hypotheses about navigation aids and learning are presented. The next section discusses the selection of a sub-set of these hypotheses for further investigation in this thesis.

3.2 Selecting Hypotheses for Investigation

In this section a sub-set of hypotheses from the framework are selected for further investigation. Hypotheses from theme 1 "Learner Involvement Facilitates Learning" and theme 5 "Tools and Signs Facilitate Learning" are selected since they form a unified piece of work that builds upon previous research on navigation and learning. This section presents the details and justifications behind this selection.

From the review of literature in chapter 2, two areas were identified for further investigation:

⇨ Research into more recent developments in navigation technology.

⇨ Studies that investigate learning from a constructivist perspective and assess the whole learning process.

These areas motivate the selection of hypotheses for investigation in this thesis. They are discussed here in relation to the hypotheses identified under themes 1 and 5 in the framework of constructivism and navigation. The selected hypotheses are then developed into a more detailed set of predictions to be investigated in the remainder of the thesis.

3.2.1 Recent Developments in Navigation Technology

3.2.1.1. Theme 1: Learner Involvement Facilitates Learning

In section 3.1.2.5, previous research on learner control over navigation was briefly discussed (Neiderhauser et al. 2000; McGrath, 1992; Becker and Dwyer, 1994) and it was argued that differences in the findings may have occurred due to differences in the definitions of learner control over navigation in these studies. Consequently, this thesis offered a definition of *navigational freedom* as one interpretation of learner control over navigation in electronic texts: the degree of choice a learner has when deciding which page to visit in an electronic text. The fact that these studies gave little focus to aggregate navigation aids was also highlighted, indicating this as an area for further investigation. Similarly, the literature review in chapter 2 suggested that a notable proportion of previous research on navigation aids and learning, especially the studies by McDonald and Stevenson, focussed on non-interactive navigation aids or early hypertext or hypermedia systems. Therefore, a natural progression from this previous research is further investigation into the effects on learning of navigational freedom as offered by different types of interactive navigation aids. This is embodied in hypothesis 1 b) i) from the framework: "Learners who use navigation aids that offer higher navigational freedom will show higher quality learning than learners who use navigation aids with lower navigational freedom".

Hypotheses about navigational freedom are also linked to hypotheses about creating navigation aids identified under theme 5. Navigational freedom is one interpretation of learner control over navigation in electronic texts. Another interpretation is to offer the learner the control to create their own navigation aids. This is discussed in the next section (section 3.2.1.2).

3.2.1.2. Theme 5: Tools and Signs Facilitate Learning

As discussed in chapter 2 and section 3.1.6.1, recent developments in navigation technology, such as Nestor Navigator, can offer the learner the opportunity to create their own navigation aids, such as maps, A-Z indices and contents lists. This gives learners control over the content, structure and layout of the navigation aid and allows them to tailor it to their own preferences.

Allowing learners to create their own navigation aids also offers them the opportunity to articulate their ideas about the electronic text content. Since there has been little previous research in this area, and due to the connection with learner control in theme 1, the investigation into the effects of allowing learners to create their own navigation aids is selected as an area for research in this thesis. More specifically, the predictions framed in hypothesis 5 b) ii) in the framework of constructivism were selected for investigation: "Learners who create their own navigation aids will show higher quality learning than learners who use existing navigation aids".

The next section expands on the selected hypotheses by framing the predictions in terms of particular aspects of the learning process.

3.2.2 Assessing Aspects of the Learning Process

Much of the experimental research on navigation and learning reported in chapter 2 assessed only the outcomes of learning through post-test performance measures. In contrast, this research takes a more constructivist approach to evaluating learning in that it accounts for the whole learning process, rather than just outcome measures. However, as pointed out by Jonassen (1991), the way that learning is evaluated is perhaps the most difficult issue for constructivism. As such, he laid out some criteria for evaluating learning in a constructivist environment (Jonassen, 1991; Jonassen, 1992):

- evaluation of learning should be goal free to overcome bias introduced by specific project goals
- higher order thinking should be assessed since knowledge construction entails higher order thinking
- if possible the process of knowledge construction should be assessed, not just the product or outcome
- evaluation should occur in rich and complex environments, similar to those used during instruction, using real-world criteria
- in line with ideas about multiple perspectives in constructivism, learning should be assessed in a way where there is no single "correct" solution
- learning should be evaluated by a portfolio of products, or measures, rather than just a single product

In keeping with these constructivist assessment criteria, this research considers learning from a number of perspectives: cognitive engagement, ownership for learning and knowledge construction. In the remainder of this section these issues are addressed in turn and the final set of hypotheses are summarised.

3.2.2.1. Cognitive Engagement

As discussed under the central claim of the framework, cognitive engagement is related to active learning, deep processing, and higher order thinking, and is fundamental to constructivist conceptions of learning. Assessing cognitive engagement offers the opportunity to examine the process of learning during the learning activity. In this research, cognitive engagement is assessed as learners use different types of navigation aids and the aim is to gain insight into the effects of navigation aids on cognitive engagement. In relation to theme 1, "Learner Involvement Facilitates Learning", Corno and Mandinach (1983) suggest that the highest forms of cognitive engagement are less likely to occur when the teacher, other students, or features of the instruction assume control over learning. Therefore, it is thought here that the higher control offered through higher navigational freedom will encourage higher levels of cognitive engagement. Similarly, in relation to theme 5, "Tools and Signs Facilitate Learning", it is thought that the opportunities for higher control and articulation offered to learners who create their own navigation aids will have benefits for cognitive engagement.

3.2.2.2. Learner Ownership

Feelings of ownership for learning were highlighted under theme 1 in the framework, "Learner Involvement Facilitates Learning", and the importance of ownership in the learning process was discussed. Assessing ownership allows insight into another aspect of the learning process. In particular, in this research measuring learner ownership will provide valuable information about the effects of navigation aids on ownership for learning. Since control was argued to be beneficial for ownership in section 3.1.2.3, it is thought that the control offered by navigational freedom and allowing learners to create their own navigation aids will have benefits for ownership.

3.2.32.3. Knowledge Construction

Finally, assessing knowledge construction, or the products of learning, is central to all forms of learning assessment. The aim in this research is to evaluate learning in a manner that is in line with Jonassen's (1991;1992) criteria. As such, the focus is on assessing knowledge transfer (the application of knowledge in new situations) and conceptual understanding, where there are no single "correct" solutions (see chapters 4, 5 and 6 for more details). As argued under theme 1 in the framework of constructivism, the control offered through navigational freedom may have benefits for knowledge construction. Similarly, the control and articulation offered by allowing learners to create their own navigation aids may also have benefits for knowledge construction.

3.2.3 Hypotheses

Following on from sections 3.2.1 and 3.2.2, this section presents expanded versions of the selected hypotheses that take account of learning in terms of cognitive engagement, feelings of ownership for learning and knowledge construction.

3.2.3.1. Navigational Freedom and Learning with Electronic Texts

Based on the arguments under Theme 1 in the framework of constructivism, "Learner Involvement Facilitates Learning" and those in sections 3.2.1 and 3.2.2, the following hypothesis was framed:

> *1. b) i) Learners who use navigation aids that offer higher navigational freedom will show higher quality learning than learners who use navigation aids with lower navigational freedom.*

This has been extended here into three more detailed hypotheses that encompass cognitive engagement, ownership and knowledge construction:

H_1 – *Learners who use navigation aids that offer higher navigational freedom will show higher levels of cognitive engagement when using an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

H_2 – *Learners who use navigation aids that offer higher navigational freedom will feel higher levels of ownership for their learning with an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

H_3 – *Learners who use navigation aids that offer higher navigational freedom will develop higher quality knowledge about the content of an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

Chapter 4 reports details of the method, results and implications of the experiment designed to test these hypotheses.

3.2.3.2. Creating Navigation Aids and Learning with Electronic Texts

Arguments from theme 5 in the framework of constructivism, "Tools and Signs Facilitate Learning", and those in sections 3.2.1 and 3.2.2, were used to frame the following hypothesis:

5 b) ii) Learners who create their own navigation aids will show higher quality learning than learners who use existing navigation aids.

This has been extended here into three more detailed hypotheses that encompass cognitive engagement, ownership and knowledge construction:

H_4 – *Learners who create their own navigation aids will show higher levels of cognitive engagement when using an educational electronic text than learners who use existing navigation aids.*

H_5 – *Learners who create their own navigation aids will feel higher levels of ownership for their learning with an educational electronic text than learners who use existing navigation aids.*

H_6 – *Learners who create their own navigation aids will develop higher quality knowledge about the content of an educational electronic text than learners who use existing navigation aids.*

Chapter 5 reports details of the method, results and implications of the experiment designed to test these hypotheses.

3.3 Chapter Summary

This chapter has presented a detailed framework of constructivism and navigation that was based on constructivist literature. This provides a broad context for experimental investigations into the effects of navigation aids on learning. The aim of the framework was to examine the implications of constructivism for navigation aids in educational electronic texts. Based on this, a number of hypotheses about the effects of navigation aids on learning were framed. A sub-set of these hypotheses was then selected for further investigation and the hypotheses were elaborated in terms of the effects on several aspects of the learning process. Experiments designed to test the hypotheses are reported in chapters 4 and 5. A further follow-on experiment is then reported in chapter 6.

4 Experiment 1: Navigational Freedom

This chapter presents a detailed experimental investigation into the effects of navigational freedom on learning with educational electronic texts.

4.1 Introduction

Learner involvement is a key theme in constructivist education, as highlighted in the framework of constructivism and navigation in chapter 3. In this thesis, learner control is proposed as one aspect of Learner Involvement that can be manipulated in the environment, and ownership is proposed as another aspect that is a resultant feeling or behaviour. Several authors argue that appropriate levels of learner control benefit learning (Eveland and Dunwoody, 2001; Milner-Bolotin, 2001; Squires, 1997). However, previous research on learner control over navigation has had mixed results. In one study, learner control over navigation was found to have benefits for aspects of learning (Becker and Dwyer, 1994), whereas in others it was found to be negatively related to learning (McGrath, 1992; Niederhauser et al., 2000). This chapter presents an experimental investigation that extends this previous research and examines the effects of one interpretation of learner control over navigation in electronic texts – navigational freedom. As discussed previously, "navigational freedom" refers to the degree of choice a learner has when deciding which page to visit in electronic texts.

The work in this chapter contributes towards **objective 3** of the thesis, "*To empirically test hypotheses that were motivated by the framework of constructivism and navigation*". In the previous chapter, the following hypotheses were developed from the framework in order to investigate the effects of navigational freedom on learning:

H_1 – *Learners who use navigation aids that offer higher navigational freedom will show higher levels of cognitive engagement when using an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

H_2 – *Learners who use navigation aids that offer higher navigational freedom will feel higher levels of ownership for their learning with an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

H_3 – *Learners who use navigation aids that offer higher navigational freedom will develop higher quality knowledge about the content of an educational electronic text than learners who use navigation aids that offer lower navigational freedom.*

An experiment was designed to investigate the effects on learning of four types of navigation aids that offer different levels of navigational freedom: paging buttons (lower navigational freedom), embedded links (medium navigational freedom), an A-Z index (higher navigational freedom) and a map (higher navigational freedom). These particular navigation aids were chosen since they are representative of typical navigation aids in educational electronic texts. Learners used one of these navigation aids to navigate an electronic text and their learning was assessed through measures of cognitive engagement, ownership and knowledge construction. Measures of navigation behaviour and usability problems were also taken and explored post-hoc for explanations of the findings on the learning measures. This chapter presents the method, analysis and results of the experiment. As mentioned in chapter 1, some data analysis was conducted in conjunction with data from experiment 2, since much of the experimental data was collected at the same time.

In order to contribute to **objective 4** described in chapter 1, *"To distil the findings of the empirical investigations into a set of implications to inform designers and researchers of educational electronic texts"*, the key implications of the findings are identified at the end of this chapter.

4.2 Method

In this experiment learners used an electronic text on the topic of *usability evaluation* with one of the following types of navigation aids: paging buttons, embedded links, an A-Z index or a map. They were initially tested to determine their prior knowledge of the topic presented in the electronic text. Then, whilst using the electronic text, participants were given a task where they had to use the information in the text to solve a problem in a given scenario. Participants were also asked to think aloud so that their level of cognitive engagement could be established from their verbalisations, and their interactions with the electronic text were recorded on video tape and in computer log files. Afterwards, their feelings of ownership for learning were measured using an ownership questionnaire and their knowledge of the text was assessed in two ways: they were asked to undertake a written "transfer" task and to hand draw a conceptual map of the electronic text. This section describes the participants, procedures and measures used in this experiment.

4.2.1 Participants

Twenty-nine students on an introductory HCI course in the spring term 2003 at City University took part in experiment 1. All had attended an introductory HCI lecture, but had not yet attended a lecture on usability evaluation (the topic presented in the electronic text). Table 4.1 shows a breakdown of the participants' demographic characteristics.

Age Range		Gender		Undergraduate/ Postgraduate		Computer Experience		WWW Experience		WWW Use	
18-29yrs.	25	Female	16	Undergrad.	10	< 1 yr.	0	< 1 yr.	0	Daily	29
30-39yrs.	4	Male	13	Postgrad.	19	1-3 yrs.	4	1-3 yrs.	3	Weekly	0
40-49yrs.	0	-	-	-	-	4-5 yrs.	3	4-5 yrs.	14	Monthly	0
50+ yrs.	0	-	-	-	-	5+ yrs.	22	5+ yrs.	12	Rarely	0

Table 4.1. The number of participants in each demographic category, and the number in each category for computer and web experience.

4.2.2 Equipment and Materials

Participants used a DELL PC running an Intel Xeon processor and 1GB RAM with a 19" monitor, keyboard and mouse. The electronic text on usability evaluation was compiled from teaching materials as well as from various HCI texts (Molich and Nielsen, 1990; Nielsen, 1994; Karat, 1994; Dix et al. 1998; Brink et al., 2002; Preece et al. 2002). The text focussed on the use of observational, heuristic evaluation and cognitive walkthrough techniques in formative evaluations and there was no set order in which the topics should be read. Usability evaluation is a major topic for an introductory HCI course and learners unfamiliar with HCI would not be expected to have much knowledge of this.

The text consisted of twenty-three pages of textual information and was approximately 3100 words in length (see appendix 4.1). The content of each page always remained the same, but the navigation aids provided were different according to the experimental condition.

Participants in all experimental conditions used the Nestor Navigator browser to access and navigate the electronic text. This was employed here because it supported the use of all four navigation aids used in this experiment and it registered navigation behaviour in log files. The log files recorded the file path, navigation aid used (e.g. embedded links or back button) and time for each page visited. As they used the electronic text, the participants' verbalisations and interactions were recorded on video camera.

4.2.3 Design and Procedure

A between-subjects design was employed and participants were randomly assigned to experimental conditions. The independent variable was the type of navigation aid. The four conditions and associated levels of navigational freedom were:

1. paging buttons (lower navigational freedom)
2. embedded links (medium navigational freedom)

3. A-Z index (higher navigational freedom)
4. map (higher navigational freedom)

See figures 4.1-4.4 for illustration. There were eight participants in the paging buttons condition and seven participants in each of the other three conditions. These navigation aids were selected for use in this experiment since they were considered representative of common navigation aids in electronic texts. The A-Z index and map conditions were both included in this experiment to represent higher levels of navigational freedom in order to assess the effects of the different structures they depict. The map shows one possible conceptual structure of the text. The A-Z index, in contrast, shows an alphabetical structure.

In the paging buttons condition, "Next" and "Previous" buttons appeared at the bottom of each page. These allowed the learner to access pages in a sequential order. In the embedded links condition each page consisted of text with embedded links and a back button, and the pages in the text were connected as a network of cross-referential links. The A-Z index condition consisted of a left-hand frame containing an interactive alphabetical list of the page titles for all twenty-three pages in the electronic text, and a right hand frame showing the content of the current page. Similarly, the map condition consisted of a left-hand frame containing an interactive graphical map of page titles that showed all twenty-three pages in the electronic text, where each map node represented a page in the electronic text, and a right hand frame showing the content of the current page.

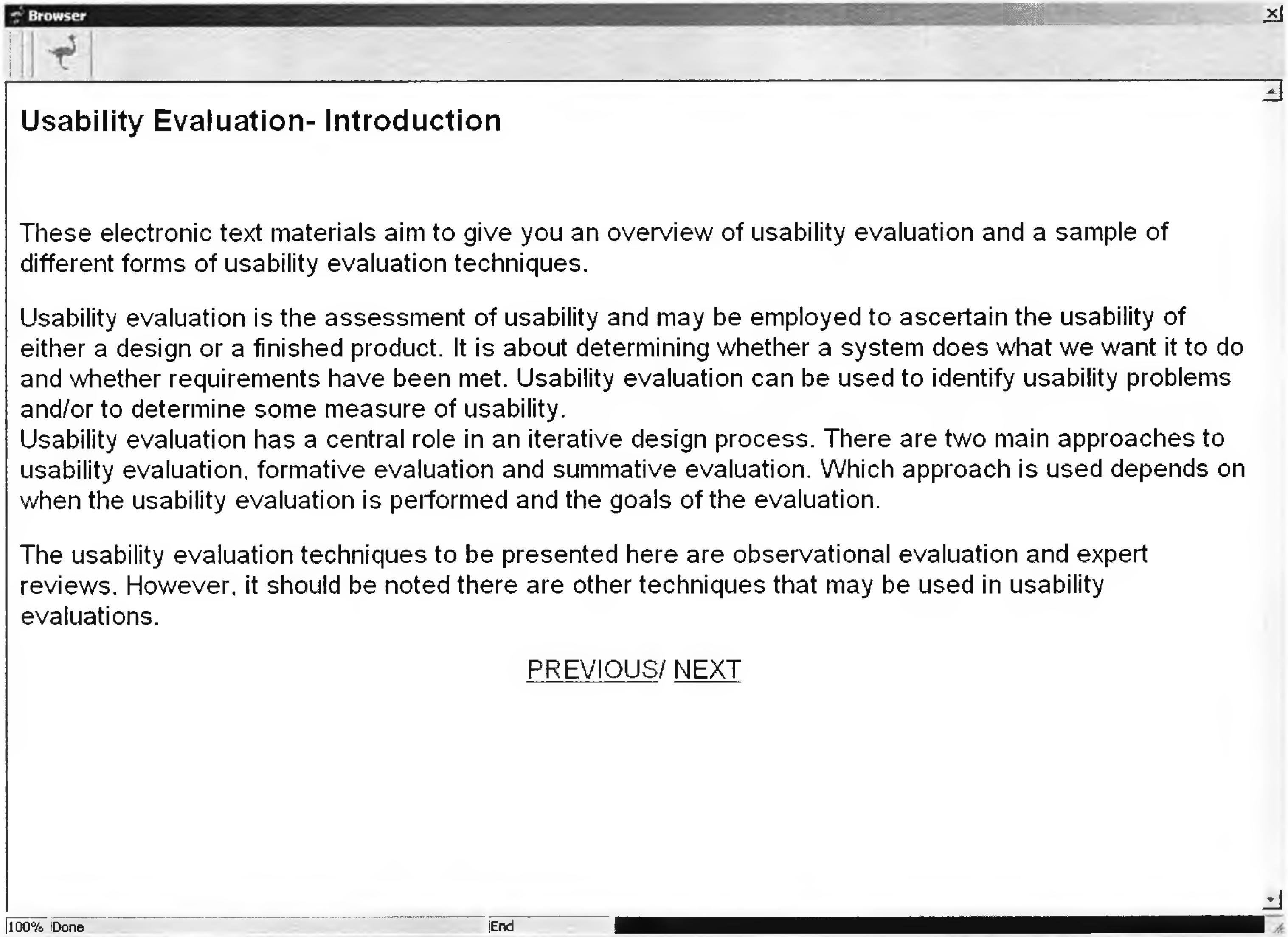

Figure 4.1. The paging buttons condition.

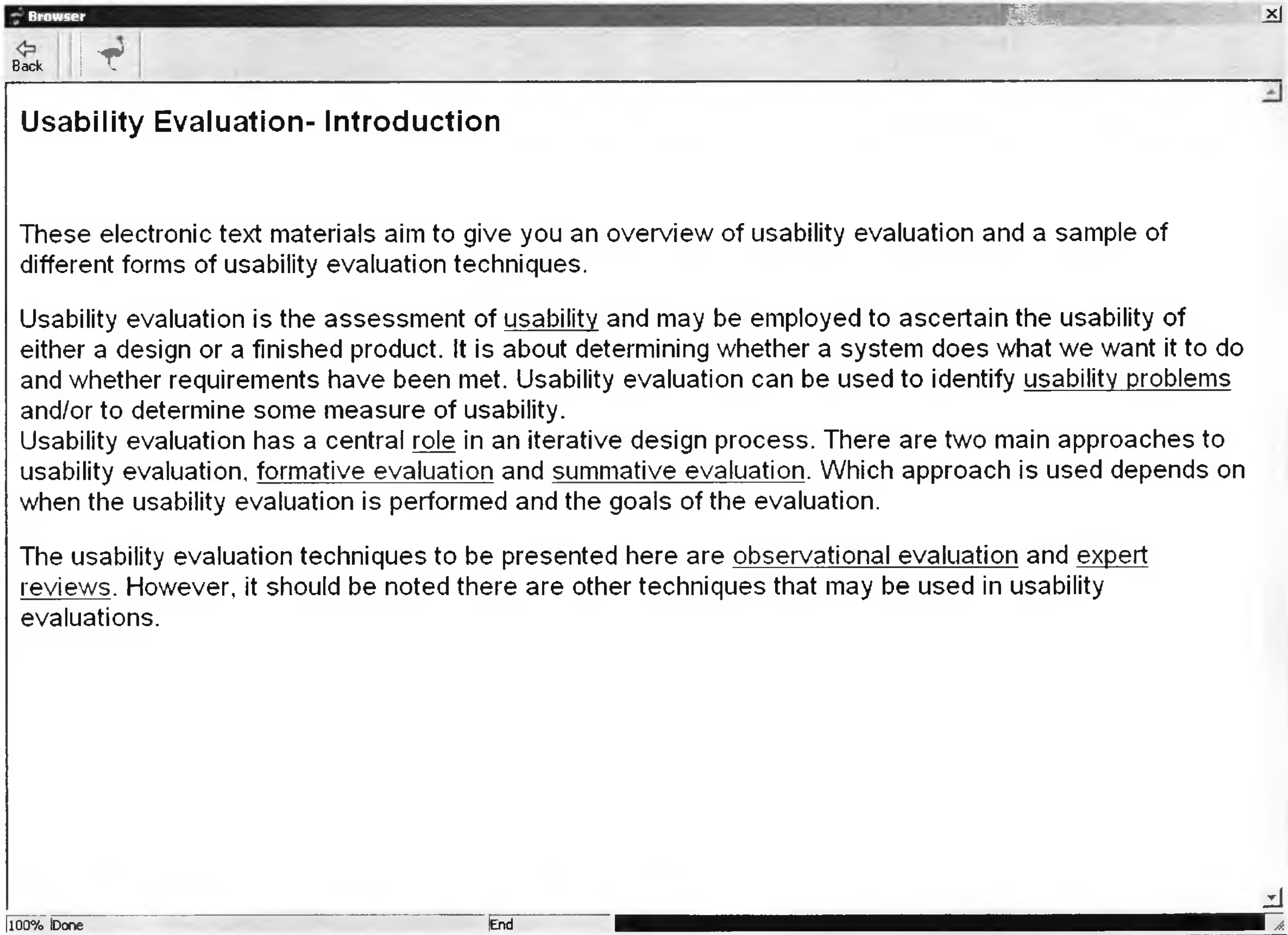

Figure 4.2. The embedded links condition.

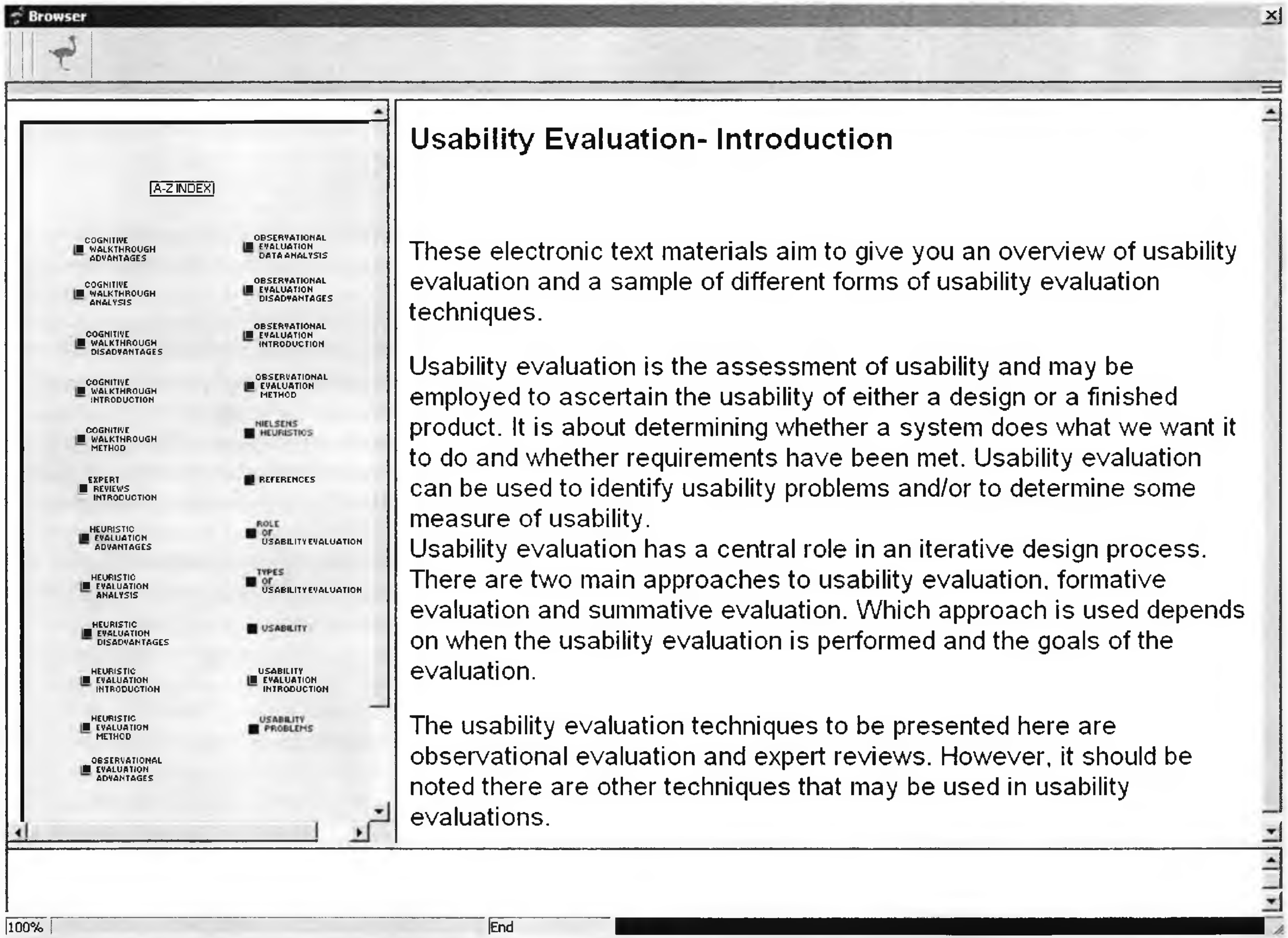

Figure 4.3. The A-Z index condition.

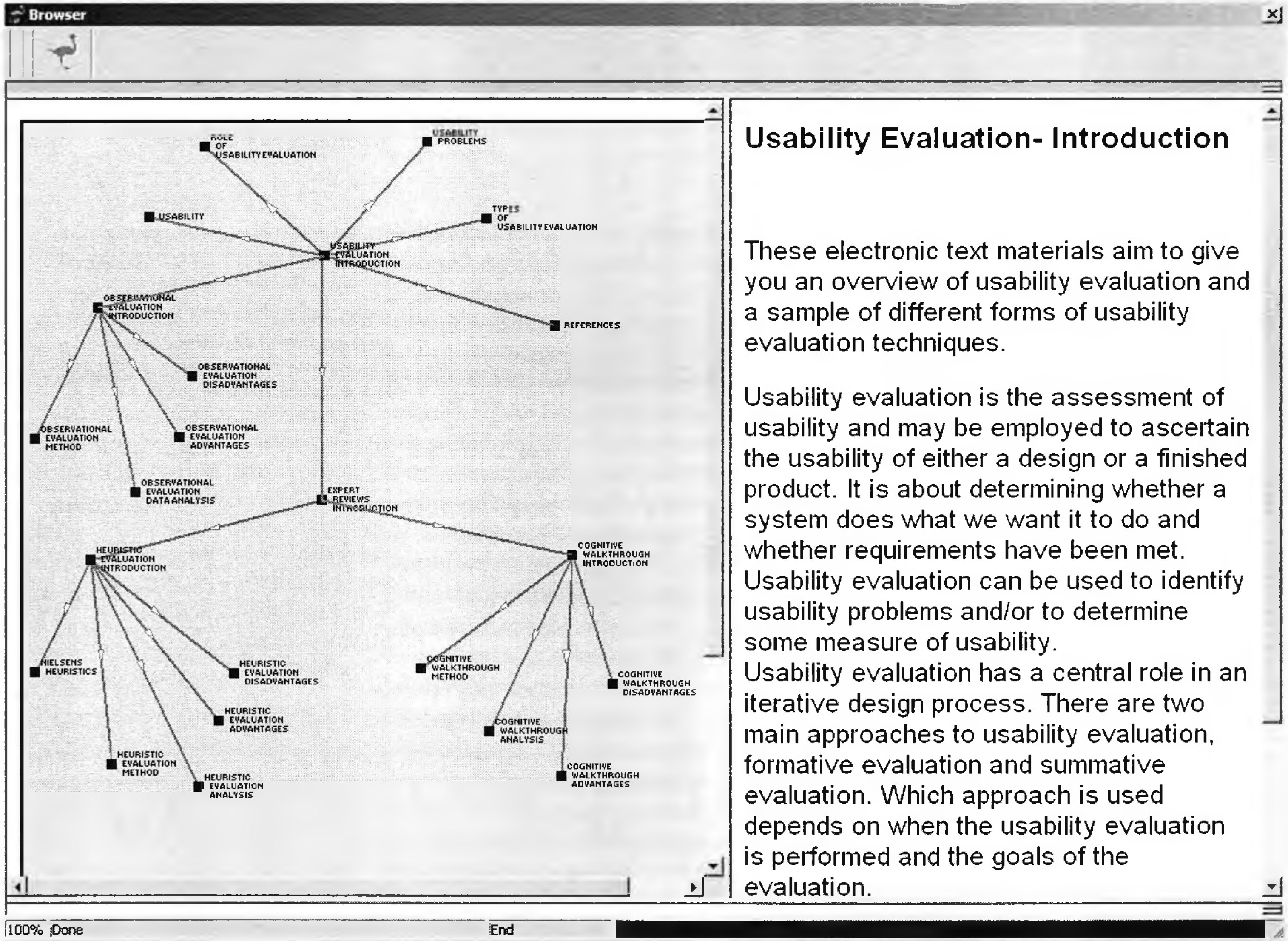

Figure 4.4. The map condition.

Participants were tested individually in a quiet environment and each experimental session lasted around two hours. An experimental script was used to ensure that the verbal instructions given to participants were consistent. The script included standardised verbal instructions and set prompts to be used for the think-aloud verbalisations (see appendix 4.2 for the experimental script). Each participant undertook the seven part experimental procedure described below. Details of the measures taken (pre-test, cognitive engagement, ownership, knowledge constructions, navigation data and usability problems) are described in sections 4.2.3.1. and 4.2.3.2.

1. Upon arrival, the participant was given introductory information about the general aims of the study and completed a consent form.
2. Demographic information was collected from the participant and a pre-test was administered (see appendix 4.3).
3. A ten-minute training task was undertaken using sample materials on the American Museum in Britain to familiarise the participant with Nestor Navigator and the navigation aid they would be using (see appendix 4.4 for the training instructions). The participant was also asked to think aloud during this training task so that they could become accustomed with verbalising their thoughts. At the end of the training task, the participant was asked whether they understood how to use the navigation aid they were provided with and any difficulties they had were addressed by the experimenter.
4. The usability evaluation electronic text was opened. The participant was asked to use the information in the electronic text to solve a usability evaluation problem. This task was intended to represent a realistic educational task. The participant was given a problem scenario in which a usability evaluation of a music shop website had to be conducted. They were given details of the available budget, timescales and access to users. They were then asked to choose a usability evaluation technique, or a combination of techniques, that would be appropriate for this evaluation scenario. They were asked to think aloud and were given up to forty-five minutes to make their decision (see appendix 4.5 for the task sheet). During periods of silence predefined probes were used to encourage the participant to continue thinking aloud. The participant's interactions with the electronic text were recorded in the Nestor log files (see appendix 4.6 for an example log file) and their think aloud verbalisations were recorded on camera.
5. The electronic text was closed and the participant was asked to complete the ownership questionnaire (see appendix 4.7).

6. The participant was asked to complete a written transfer task (see appendix 4.8 for the task sheet). They were given up to thirty minutes to complete this task.
7. The participant was then asked to complete the concept mapping task (see appendix 4.9 for the task sheet). They were given up to ten minutes to complete this task.

After completion of all experimental tasks, the aims of the experiment were explained to each participant and they were given the choice of receiving copies of any publications or reports on the experimental findings.

4.2.3.1. Learning Measures

The pre-test was administered to participants as a control measure to determine whether they all had the same level of background knowledge of the content of the electronic text. This consisted of the following seven questions testing their knowledge of usability evaluation:

1. What is usability?
2. What is a usability problem?
3. What is the purpose of usability evaluation?
4. What is formative usability evaluation?
5. What is summative usability evaluation?
6. List as many usability evaluation techniques as you can.
7. Give brief details of the techniques you have listed and how they might be used in formative usability evaluations.

In order to test $\mathbf{H_1}$, higher navigational freedom leads to higher levels of cognitive engagement, the participants' level of cognitive engagement whilst using the electronic text was assessed from their think aloud verbalisations. Each participant's verbalisations were transcribed from video tapes. Details of how these were transcribed and analysed are described in section 4.3.1.2.

To test $\mathbf{H_2}$, higher navigation freedom leads to higher feelings of ownership, an ownership measurement questionnaire designed for measuring ownership in a classroom setting (Milner-Bolotin, 2001) was adapted for use in the context of educational electronic texts. The original questionnaire included statements that assessed ownership for learning in a group project. The process of adapting the questionnaire involved rewording the statements in terms of issues specific to the use of electronic texts in learning. In accordance with Milner-Bolotin's (2001) definition of ownership, the adapted questionnaire consisted of sixteen statements on feelings of control for learning, feelings of responsibility for learning and feelings of value for learning (see appendix 4.7). Participants were asked to rate their responses on a five-point Likert scale from strongly disagree (1) to strongly agree (5). A reliability analysis and factor analysis were performed on the questionnaire to ensure that the questionnaire was a reliable and valid measure of ownership. This analysis is discussed in section 4.3 of this chapter.

To test **H_3**, higher navigational freedom leads to higher quality knowledge constructions, participants' knowledge construction was measured in two ways: performance on a written transfer task and performance on a concept-mapping task.

The written transfer task assessed participants' ability to apply the knowledge they developed when using the electronic text to another usability evaluation scenario. The new scenario concerned conducting a usability evaluation for memo software on a mobile phone. Participants were asked to write a report explaining which usability evaluation technique they would recommend for use in this scenario, including details of: what usability evaluation is; the techniques presented in the text; their chosen technique(s); an explanation of why their chosen technique(s) were suitable for the given setting; and a brief description of how they would be employed (see appendix 4.8). Similar transfer task measures have been used in previous studies of e-Learning (e.g. Williams et al., 2001).

The concept-mapping task, on the other hand, assessed the participants' knowledge of the content and the conceptual structure of the electronic text. Similar concept-map measures have been used to assess knowledge in previous research on learning with electronic texts (e.g. McDonald and Stevenson, 1997b; Stanton et al. 1992; Shapiro, 1998). Participants were asked to produce a hand-drawn concept map on usability and usability evaluation techniques from the information they had gleaned from the electronic text (see appendix 4.9).

In line with a constructivist view of learning, all of these measures were intended to evaluate the participants' learning at a deeper level than that captured by the performance measures that have been used in previous experimental studies of navigation and learning, such as factual knowledge questions (see chapter 2).

Details of the analysis of the learning measures are described in section 4.3.1.

4.2.3.2. Navigation and Usability Problem Measures

Navigation behaviour and usability problem measures were employed in this experiment to explore potential explanations for findings on the learning measures. Log-files recorded navigation behaviour in the Nestor Navigator browser and post-hoc analyses were performed on this data.

In addition, post-hoc analyses were performed on the transcriptions of the participants' think-aloud verbalisations for evidence of usability problems experienced whilst participants used the electronic texts. Details of these analyses are described in section 4.3.2.

4.3 Analysis

This section presents the data analysis. Steps taken to ensure the reliability and validity of each measure are also discussed.

4.3.1 Learning Measures

This section describes analyses for the pre-test, cognitive engagement, ownership and knowledge construction measures taken to test $H_1 - H_3$. As mentioned earlier, some of the data analysis was performed together with data collected from experiment 2. The data was checked together because it was analysed at the same time and the procedures and measures were the same in experiment 2 as in experiment 1. To check the reliability and validity of each measure the data for the pre-test, ownership questionnaire, written transfer task and concept mapping task in experiment 1 was pooled with the data from the conditions in parts A and B of experiment 2. This gave a total of fifty-eight pre-tests, fifty-eight ownership questionnaires, fifty-eight written transfer tasks and fifty-eight concept maps.

To ensure the reliability and validity of the cognitive engagement measures, the think aloud transcripts in experiment 1 were pooled with those from parts A, B and C experiment 2 during the analysis, making a total sample pool of seventy-one transcripts from all the participants in these experiments (twenty-nine from experiment 1, and forty-two from experiment 2). Again, this was done because the analysis of these measures was performed at the same time and the procedures and measures were the same in experiments 1 and 2.

4.3.1.1. Pre-test

The pre-test assessed participants' existing knowledge of usability evaluation. The questions were marked by the author and the marks were summed to give an overall mark for each participant's expertise in usability evaluation calculated as a percentage (see appendix 4.10 for the marking scheme). To check the reliability and validity of the marking, an expert in usability evaluation external to this research independently marked a random sample of fifteen pre-tests from the total pool of fifty-eight from experiment 1 and parts A and B of experiment 2. Due to the non-parametric nature of the pre-test marks, a Spearman's rank correlation was employed to check how well the marks corresponded. This revealed a significant correlation between the two marks ($rho(105)=0.834$, $p=0.000$) (see appendix 4.11 for details of the outputs of this analysis). Therefore, the marking was reliable and valid.

For the findings of the pre-test see section 4.4.1.

4.3.1.2. Cognitive Engagement

Participants' think aloud verbalisations whilst using the electronic text were transcribed word for word from the video tapes. The tape counter and the page in the electronic text where the participant made the verbalisation were recorded, and any aspect of the interface that the participant referred to in their verbalisations was also noted. However, no details of any of the participants' physical actions (e.g. what pages they clicked on) were transcribed unless they made reference to them in their verbalisations.

A coding scheme was developed to identify cognitive engagement activities from the transcripts (see table 4.2). This was based on Corno and Mandinach's (1983) components of self-regulated learning and Stoney and Oliver's (1999) categories of higher order thinking (see chapter 3). The application of the coding scheme involved examining the transcripts in detail and assigning one or more codes to comments that were considered to be related to cognitive engagement activities. In doing this, a comment was defined to be part of a sentence, or one to two sentences in succession that related to the same theme or concept.

Activity	Code	Definition	Typical transcript excerpts
Alertness	A	Comments regarding the tracking/gathering/noticing of important information in the electronic texts and recognising what information in the electronic texts is about. Discriminating among information presented in the electronic texts, distinguishing relevant from irrelevant information. Note that this is not just stating the name of the page they are on.	*"It looks like there's two alternatives there, one of them's cognitive walkthrough, the other one's heuristic evaluation introduction".*
Planning/ Strategy	P	Comments related to considering strategies for exploring the electronic texts and planning the sequence that they will visit pages in the text. Considering strategies for using the electronic texts in the task. Note: this relates to groups of pages, not just single pages i.e. "I'm going to heuristic evaluation advantages" is not planning.	*"... I'm just going to go down this map fairly systematically so the next thing that I click on is the observational evaluation introduction."*
Connecting Experiences	CE	Comments related to making connections between concepts within the text, or to real world knowledge/experience and prior knowledge, including comments about the task as a real world problem. Going beyond the text content.	*"I recognise this definition from my course." "Yeah, it's [formative evaluation] a bit like a lifecycle [...] and you can use the different methods [...]and end up with your summative evaluation" "So this one [heuristic evaluation] goes with the expert... expert reviews".*
Connecting to the Task Setting	CT	Any comments where text content is considered in terms of factors in the task setting (considering information about a given technique and how this relates to the factors in the task setting). Including relating the text content to factors in the task setting while selecting a final usability evaluation technique.	*"[An alternative to performing usability evaluations with real users to get experts to identify usability problems.] Well now there's a bit of an issue here, because my three colleagues, who I guess are the experts, aren't available 'cause they're too busy. So we might have a problem down this end anyway, just getting people to do it."*
Monitoring Understanding	MU	Comments related to continuous tracking and self-checking understanding of the text content and comments confirming that they understand the text content. More than just simple 'ok'. Can apply to the entire task.	*"OK I now understand what formative evaluation is about."*
Monitoring Navigation	MN	Any comments of tracking/checking of navigation, summaries of where they have been in the electronic texts. Refers to tracking a group of pages, rather than single pages, and involves checking if they have missed anything. Note: this is not simply stating single actions that they have just done (e.g. "I have just been to Usability Evaluation Introduction"). Can include comments related to creating/rearranging navigation aids.	*"Ok, so that's evaluation methods, evaluation analysis we've looked at."*
Critiquing Text Content	CTC	Any comments related to the quality of the text content including how informative it is and the quality of explanations and definitions. Comments about whether they agree/disagree with ideas in the text, or making judgements about ideas in the text.	*"This definition [of usability] doesn't really stress the importance of... that it should be implemented in the earlier stages of testing... the material. [...] It is a bit vague."*
Restating Understanding	RU	Restating information in the text and showing understanding i.e. putting text content into their own words. Not simply reading aloud.	*"So formative is basically about product improvement, summative is performed on final designs at the end, measures the usability of a very final product."*
Selecting Technique	ST	Any comments related to the selection of a usability evaluation technique, or combination of techniques, with or without explanation (including saying whether they think a technique is good or bad, or discussing the advantages/disadvantages). Note: this can co-occur with CE and CT.	*"OK so at this point I think that we need some heuristic evaluation to take place."*
Employing Selected Technique	EST	Comments related to how a technique will be employed in the task setting. Includes comments about the ordering of the techniques, choosing users and tasks, and adapting heuristics. These comments can include those made during the use of the electronic texts or at the end of the task in the decision summary.	*"So I'm thinking that we're definitely going to do the observational ... including the interviews, may be a questionnaire, I'm not sure about the questionnaire, but certainly an interview after the observational bit."*

Table 4.2 Coding scheme for cognitive engagement activities.

The original coding scheme was developed by the author. To ensure the validity of the scheme two further individuals gave input during its development. A random sample of three transcripts was taken from the pool of seventy-one transcripts from experiments 1 and 2. These transcripts were then coded independently by the author and two other experts in HCI using a first draft of the coding scheme. The author then discussed the codings with the HCI experts and considered any areas where different codes had been applied and the way in which the codes had been interpreted. The coding scheme was then revised to address issues that arose during these discussions of these independent codings. An example revision to the scheme was that a redundant code called "Predicting", which was intended to code for activities where the participant predicted what would come next in the electronic text, was removed since its application was so infrequent. Another example revision was in the way that the coding scheme was applied. It was decided that any sections of the transcripts where participants were simply reading aloud from the electronic text should not be coded. The final coding scheme is summarised in table 4.2 (see appendix 4.12 for a more detailed version of the coding scheme, including notes on how it should be applied). In order to make the final coding of all of the transcripts in experiments 1 and 2 as reliable as possible, the author checked the coding applied to each transcript twice (see appendix 4.13 for an example transcript coded according to the final coding scheme).

The level of cognitive engagement for each participant was calculated based on the number of coded activities within each transcript. Some activities required more complex mental operations than others and these activities were given a score of two, whereas all others were given a score of one (see table 4.3). The sum of scores for all the activities was then calculated for each transcript to give a total *cognitive engagement score*. The aim of this score was to reflect the level of cognitive engagement shown in each participant's verbalisations. The cognitive engagement data for experiment 1 was then analysed in terms of frequency of each higher order engagement activity in each transcript and the total cognitive engagement scores for each transcript. An average frequency for each cognitive engagement activity was calculated for each condition and an average total cognitive engagement score was then calculated for each condition.

Score	Activities
1	Alertness (A) Employing Selected Technique (EST) Monitoring Navigation (MN) Restating Understanding (RU) Selecting Technique (ST)
2	Connecting Experiences (CE) Connecting to the Task Setting (CT) Critiquing to Text Content (CTC) Monitoring Understanding (MU) Planning/Strategy (P)

Table 4.3 Scores for cognitive engagement activities.

A non-parametric Kruskal-Wallis one-way analysis of variance (ANOVA) by ranks was employed to assess the differences across conditions for the cognitive engagement scores and the number of instances of each of the individual cognitive engagement activities. The results of these analyses are described in section 4.4.1.

4.3.1.3. Ownership

The ownership questionnaire administered to participants consisted of sixteen statements (see appendix 4.7) and there were five stages to its analysis.

1. The first stage consisted of an analysis of the internal reliability of the questionnaire. This was to assess the quality of the questionnaire and to ensure that all statements related to the same construct – ownership for learning with electronic texts. The internal reliability analysis involved checking ratings for each statement against ratings for the questionnaire as a whole. This included examination of all ratings from the total pool of fifty-eight ownership questionnaires from experiment 1 and parts A and B of experiment 2. If the ratings for a statement had a low correlation with ratings on the entire questionnaire, otherwise known as low item-total correlation, this indicated that it may have measured a different construct to the other statements on the questionnaire. This process led to the removal of three statements due to low-item total correlations (see box 4.1 for the removed statements). The final questionnaire, used in the following analyses, consisted of thirteen questions and was found to have a Cronbach's alpha of 0.8, indicating good internal reliability (see appendix 4.14 for further details of the output of the reliability analysis).
2. In the second stage of the analysis, a confirmatory factor analysis was conducted to determine how the statements grouped into factors. A factor refers to a sub-group of statements on the questionnaire that relate to the same thing, in that they inter-correlate highly with each other. The factor analysis also checks the validity of the questionnaire since it determines whether the responses to statements group in a predictable manner (e.g. it checks whether responses to all statements on feelings of control group together). The factor analysis revealed three factors: feelings of control over use of the electronic texts; feelings of responsibility for learning with the electronic texts; and feelings of value for learning with the electronic texts (see appendix 4.15 for details of the output of this analysis). The fact that the results of the factor analysis revealed meaningful factors indicates that the validity of the questionnaire is good. See box 4.1 for the statements that fell under each factor.

3. In the third stage of the analysis, the total ownership rating for each participant was calculated. This involved three steps.
    a. The ratings for negatively worded statements (labelled "**R**" in box 4.1) were reversed. For example, a rating of *5* on a negatively worded statement would be replaced by a *1*.
    b. The ratings for the thirteen statements were added together giving a score out of sixty-five.
    c. The sum of the ratings was divided by thirteen to give an average rating for each participant out of five – this was the total ownership rating.
4. In the fourth stage of the analysis, the average total ownership for each condition was calculated and the questionnaire responses were then examined in terms of average ratings for each factor in each condition. Average ratings for the control factor were calculated by pooling the ratings for the five control statements from all participants and then calculating an average for each condition. The same method was used to obtain average ratings for the responsibility and value factors.
5. In the final stage of the analysis, Kruskal-Wallis ANOVAs were employed to assess differences across conditions for total ownership, and the control, responsibility and value factors. Where appropriate non-parametric tests for post-hoc pair-wise comparisons were also conducted using the Siegal and Castellan (1988) method. See section 4.4.1 for the results of these analyses.

Factor 1 – Feelings of Control

I felt I could not access the pages I wanted to in the electronic texts. **[R]**

I felt I was free to choose the way I progressed through the electronic text materials.

I felt I had control over the use of the electronic text.

I think I had control over my progression through the electronic text materials.

I felt responsible for the exploration of the materials on usability evaluation.

Factor 2 – Feelings of Responsibility

I felt responsible for my final choice of evaluation technique(s).

I felt ownership for my final choice of usability evaluation technique(s).

I do not feel a personal responsibility for the decisions I made when using the electronic texts to choose a usability evaluation technique. **[R]**

I feel responsible for the usability evaluation decisions I made when using the electronic text.

I had a sense of ownership for my use of the electronic text materials to choose a usability evaluation technique(s).

Factor 3 – Feelings of Value

I found no personal value in the information in the electronic texts. **[R]**

I found personal value in the use of the electronic text.

I think I will be able to use what I have learned from the electronic text materials in other courses, and/or in everyday life.

Removed Statements

I felt that my progression through the electronic text materials was guided.

I think that the skill I have learned when using these material will help me to succeed in the future.

I think freedom to decide the way you use electronic text materials is very important to learning with these materials.

Box 4.1 Statements that fell under each factor and statements that were removed from the ownership questionnaire. Reversed statements (negative wording) are marked by "R".

4.3.1.4. Knowledge Construction

A detailed marking scheme was developed for the written transfer tasks (see appendix 4.16) and each written transfer task was marked by the author. The total mark for each transfer task was calculated by marking each of the following aspects out of five, adding up these marks and converting the marks to percentages.

A – Description of usability evaluation and its purpose

B – Details of the evaluation techniques presented in the electronic text

C – Understanding of how the usability evaluation techniques relate to each other

D – Explanation of how each technique relates to the given usability evaluation setting

E – Details of how the chosen technique will be employed

F – Argument quality

The results of these analyses are reported in section 4.4.1.

In order to check the reliability of the marking, an expert in usability evaluation external to this research marked a random sample of fifteen written transfer tasks from the total pool of fifty-eight from experiment 1 and parts A and B of experiment 2. Due to the non-parametric nature of the marks, a Spearman's rank correlation was employed to check how well the two sets of marks corresponded. This revealed a significant correlation between the two sets of marks (rho(15)=0.853, p=0.000) (see appendix 4.17 for further details of the outputs of this analysis). This suggests that the marking was reliable and that the marking scheme had good validity.

Kruskal-Wallis ANOVAs were employed to assess differences across conditions for all aspects that the transfer tasks were marked on, and where appropriate non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. See section 4.4.1 for the results of these analyses.

The concept maps were assessed in two ways: they were given a quantitative mark and a qualitative mark. The quantitative mark was the total number of nodes and links represented in the map. This aimed to objectively assess the level of *detail* in the concept maps. The qualitative mark, on the other hand, was concerned with the *quality* of the map and a detailed marking scheme was developed to assess this (see appendix 4.18). The author marked the concept maps according to the marking scheme and the qualitative marks were converted to percentages. The results of these analyses are reported in section 4.4.1.

To check the reliability of the qualitative marks, a random sample of fifteen concept maps were taken from the total pool of fifty-eight from experiment 1 and parts A and B of experiment 2, and were second marked by an expert on usability evaluation who was external to this project. A Spearman's rank statistic was then calculated. This revealed significant correlations for the two sets of marks on the relevance of nodes (rho(15)=0.600, p=0.009) and the appropriateness of the link structure (rho(15)=0.496, p=0.030) (see appendix 4.19 for details of the output of these analyses). This suggests that the marking was reliable and that the marking scheme had good validity.

The quantitative marks were analysed using a parametric ANOVA and Tukey post-hoc pair-wise comparison tests. The qualitative marks were analysed using a Kruskal-Wallis ANOVA and post-hoc pair-wise comparisons using the Siegal and Castellan (1988) method. See section 4.4.1 for the results of these analyses.

4.3.2 Navigation and Usability Problem Measures

This section presents post-hoc analyses performed to further explore participants' behaviour during the experiments. Measures of navigation behaviour and usability problems were taken. The aim of these measures was to determine if the way that participants used the navigation aids, and any usability problems they experienced, could help explain the findings on the learning measures. This was done by examining whether any differences between conditions on the navigation behaviour measures or the usability problem measures corresponded with differences on any of the learning measures.

The log files were analysed for navigation behaviour in two ways in this experiment: the average total number of operations (clicks[1]) for each condition; and the average number of different pages visited for each condition. Differences across conditions for both of these measures were then assessed. These measures were determined as basic measures of navigation behaviour and have been used in previous research on electronic texts (McDonald and Stevenson, 1997b; McDonald and Stevenson, 1998; Stanton et al., 1992; Wenger and Payne, 1994; Nilson and Mayer, 2002; Danielson, 2002; Gupta and Gramopadhye, 1995; see chapters 2 and 3 for details). Other measures of navigation used in previous research, concerning the efficiency with which participants reached target information (e.g. Smith, 1996; McDonald and Stevenson, 1997a; McDonald and Stevenson, 1999), were not considered relevant here. The participants in this experiment were not searching for target information to complete their task as they used the electronic text; instead participants needed to integrate information from several pages in the text to achieve their task.

The number of operations were analysed using a parametric ANOVA and Tukey post-hoc pair-wise comparison tests. However, for the number of different pages visited, a Levene test for homogeneity of variance indicated that the variances were significantly different between conditions. Accordingly, a non-parametric Kruskal-Wallis ANOVA was employed to assess the differences between conditions. The results of these analyses are reported in section 4.4.2.

Instances of usability problems were identified from the think aloud transcripts. The criteria used to identify usability problems are set out in box 4.2. Initially a draft set

[1] Each click indicated that a navigation aid had been used. However, this did not necessarily mean that the page had changed from the previously displayed page. For example, an operation would be recorded when a participant clicked on a page on the A-Z index, even if it was the same page that was currently being displayed.

of criteria were developed by the author from a set of possible negative effects of a system on a user given in van Rens (1997) (cited in Andre et al. 2001, also see the Virginia Tech HCI website[2]) and were elaborated to accommodate the nature of the participants interactions' with the electronic texts here. Two other individuals were also checked these criteria to ensure their validity. The three transcripts that were taken from the pool of seventy-one transcripts from experiments 1 and 2 to develop the cognitive engagement coding scheme were also used to check the criteria for identifying usability problems. The transcripts were independently coded for usability problems by the author and two other experts in HCI using the draft set of criteria. The coding involved examining the transcripts for comments that related to the criteria. Any issues that arose in the independent codings were discussed with the two experts and the criteria were revised based on these discussions. This included clarifying definitions and removing overlapping criteria. In order to ensure that the application of the final criteria was as reliable as possible, the final coding of all the transcripts from experiments 1 and 2 was checked twice by the author. See appendix 4.20 for an example transcript coded for usability problems.

1. Interface Problems

1.1. Verbalisations show evidence of dissatisfaction about an aspect of the interface.
1.2. Verbalisations show evidence of confusion/uncertainty about an aspect of the interface.
1.3. Verbalisations show evidence of confusion/surprise at the outcome of an action.
1.4. Verbalisations show evidence of physical discomfort.
1.5. Verbalisations show evidence of fatigue.
1.6. Verbalisations show evidence of difficulty in seeing particular aspects of the interface.
1.7. Verbalisations show evidence of that they are having problems achieving a goal that they have set themselves, or the overall task goal.
1.8. Verbalisations show evidence that the user has made an error.
1.9. The participant is unable to recover from error without external help from the experimenter.
1.10. The participant makes a suggestion for redesign of the interface of the electronic texts.

2. Content Problems

2.1. Verbalisations show evidence of dissatisfaction about aspects of the content of the electronic text.
2.2. Verbalisations show evidence of confusion/uncertainty about aspects of the content of the electronic text.
2.3. Verbalisations show evidence of a misunderstanding of the electronic text content (the user may not have noticed this immediately).
2.4. The participant makes a suggestion for re-writing the electronic text content.

Box 4.2 Criteria for identifying usability problems from verbal protocol transcriptions.

Each usability problem instance identified in the transcripts was given a severity rating from 1-4. The severity ratings were adapted from Nielsen (1999) for use in the context of this study and were worded in terms of the effect that they had on the participant's ability to complete the experimental task (choosing a usability evaluation technique for the music shop website using the information in the electronic text) (see

[2] http://research.cs.vt.edu/usability/projects/uaf%20and%20tools/upc.htm (visited 10/08/04).

table 4.4). The total number of problem instances experienced by each participant was determined and the average number of problem instances per participant for each condition was calculated. For the results of these analyses see section 4.4.2.

Severity	Description
1	**Cosmetic problem.** No impairment of task performance.
2	**Minor usability problem.** Some impairment of task performance.
3	**Major usability problem.** Severe impairment of task performance (including misunderstandings of the electronic text content).
4	**Usability catastrophe.** The participant cannot continue with their task, or the participant completely misunderstands several concepts in the electronic text.

Table 4.4 Severity ratings for usability problems identified from participants' verbal protocols.

Since some problems occurred repeatedly, duplicate problems were matched for each participant. Accordingly, if a problem occurred more than once in the transcript for a participant then the problem descriptions were combined into a single "unique" problem that was unique in terms of its cause or the effect it had on the participant. As such, two participants within any condition could experience the same "unique" problem, since the problems were only determined to be unique in terms of the problems experienced by each individual participant. The criteria shown in table 4.5 were used to match the problems and were adapted from a set detailed in Dimitrova (2002). The number of unique problems for each participant was then determined and the average number of unique problems per participant was calculated for each condition. For the results of these analyses see section 4.4.2.

Once the unique problems were identified, the severity ratings were reassigned taking into account the frequency of the problems. For problems that occurred three times or more consideration was given as to whether the problem should be assigned a higher severity rating. Total severity ratings were calculated for each participant by summing the severity ratings for each unique problem for each participant. An average was then calculated for each condition.

The number of instances per participant, number of unique problems per participant, and total severity per participant were analysed using Kruskal Wallis ANOVAs to assess differences across conditions. For the results of these analyses see section 4.4.2.

Problem Matching Criteria
Both describe the same fault with the same design feature, although it may be observed in a different part of the electronic text.
Both describe the same breakdown in participant interaction.
Both describe the same participant behaviour.
One describes a breakdown and the other describes an effect on participants caused by the same design feature.
Both describe the same or very similar design solutions.

Table 4.5 Criteria for matching problems identified from verbal protocols.

Finally, the unique usability problems were categorised into the types of problems that occurred in each condition. This was done by initially grouping the problems into those that concerned the content of the electronic text and those that concerned the interface. These categories were then refined and categories were added that were unique to particular conditions. Table 4.6 gives a description of each category of usability problems. Next, for each category that occurred within each condition, the average number of unique problems per participant in each severity rating was calculated. For the results of these analyses see section 4.4.2.

Category Name	Category Description
General Confusion	Problems concerning general confusion about the use of the electronic text (where the exact cause is unclear).
Hardware	Problems concerning the hardware used during the experiment including problems with reading off the screen and using the mouse.
Text Content	Problems concerning the quality of the text content in terms of how useful it is and how it may be improved. **N.B.** This does not include problems understanding the content of the electronic text.
Text Presentation	Problems concerning the presentation of the electronic text.
Using Aggregate Navigation Aid	Problems specific to navigating and interacting with an aggregate navigation aid (e.g. map or A-Z index).
Navigation Predicting	Problems arising when the participant was unable to make predictions about navigating the text such as uncertainty about where hyperlinks will take them.
Navigation Disorientation	Problems where the participant appeared to be lost in the electronic text, including problems getting an "overall picture" of the electronic text.
Navigation Text Structure	Problems concerning the structure of the electronic text and the order in which pages can be read in.
Navigation Efficiency	Problems of inefficient navigation including problems finding information in the electronic text and problems deciding where to go next.
Understanding Text	Problems understanding the content of the electronic text.
Other	General comments about using the electronic text in the task and how they would normally use the electronic text outside of the experiment.

Table 4.6. Categories of usability problems identified from participants' verbal protocols.

4.4 Results

This section presents the findings for the learning measures taken to test H_1-H_3. In addition, the results of the post-hoc analyses of the participants' navigation behaviour from log files, and usability problems extracted from participants' think aloud verbalisations are presented. Where inferential statistics are presented, statistical significance is set at the 0.05 level for all analyses. Graphs are only shown when statistically significant differences, borderline differences, or differences approaching significance[3], are found, and include error bars showing +1 standard error.

4.4.1 Learning Measures

4.4.1.1. Pre-test

The mean of the overall marks for the seven pre-test questions on usability evaluation was 16.39%. The standard deviation was 14.36. One participant in the paging buttons condition received an overall mark of 66%. This was determined to be an extreme case, since the overall mark was three standard deviations above the mean, and as such the data for this participant was removed from subsequent analyses.

4.3.1.2. Cognitive Engagement

The results of the analyses of cognitive engagement are summarised in table 4.7 (further details of the output of these analyses are given in appendix 4.21).

Analysis	Average for each condition	Kruskal-Wallis ANOVA
Cognitive engagement scores	paging buttons – 76.14; embedded links – 77.43; A-Z index – 65.71; map – 68.43.	Non-significant.
Planning/Strategy (instances)	paging buttons – 0.86; embedded links – 1.71; A-Z index – 3.43; map – 1.71.	Non-significant.
Connecting to the Task Setting (instances)	paging buttons – 5.14; embedded links – 2.43; A-Z index – 2.14; map – 5.00.	Non-significant.
Connecting Experiences (instances)	paging buttons – 12.14; embedded links – 11.14; A-Z index – 8.57; map – 8.57.	Non-significant.
Critiquing Text Content (instances)	paging buttons – 1.71; embedded links – 2.71; A-Z index – 1.71; map – 1.43.	Non-significant.
Monitoring Understanding (instances)	paging buttons – 5.43; embedded links – 5.14; A-Z index – 2.71; map – 3.86.	Non-significant.
Employing Selected Technique (instances)	paging buttons – 3.43; embedded links – 3.29; A-Z index – 4.43; map – 3.29.	Non-significant.
Restating Understanding (instances)	paging buttons – 8.71; embedded links – 11.43; A-Z index – 8.57; map – 10.00.	Non-significant.
Alertness (instances)	paging buttons – 5.00; embedded links – 2.71; A-Z index – 6.43; map – 3.29.	Non-significant.

[3] *Borderline significant differences* were determined to be those where $0.05 \le p \le 0.06$. *Differences approaching significance* were determined to be those where $0.06 \le p \le 0.08$.

Selecting Technique (instances)	paging buttons – 6.57; embedded links – 7.29; A-Z index – 5.71; map – 7.71.	Non-significant.
Monitoring Navigation (instances)	paging buttons – 1.86; embedded links – 6.43; A-Z index – 3.43; map – 3.00.	Non-significant.

Table 4.7 Results of analyses for cognitive engagement.

4.4.1.3. Ownership

The results of the analyses of the ownership questionnaire are summarised in table 4.8 (see appendix 4.22 for further details of the outputs of these analyses).

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total ownership scores (out of 5)	paging buttons – 3.83; embedded links – 3.78; A-Z index – 4.07; map – 3.89.	Non-significant.	N/A.
Control factor (out of 5)	paging buttons – 3.34; embedded links – 3.54; A-Z index – 4.40; map – 4.17. **(see figure 4.5).**	**Significant** (H(3,140)=20.83,p=0.000)	paging buttons vs A-Z; paging buttons vs map; embedded links vs A-Z; embedded links vs map.
Responsibility factor (out of 5)	paging buttons – 3.91; embedded links – 3.97; A-Z index – 3.57; map – 3.54.	Non-significant.	N/A.
Value factor (out of 5)	paging buttons – 4.43; embedded links – 3.86; A-Z index – 4.33; map – 4.00.	Non-significant.	N/A.

Table 4.8 Results of analyses performed on the ownership questionnaire ratings.

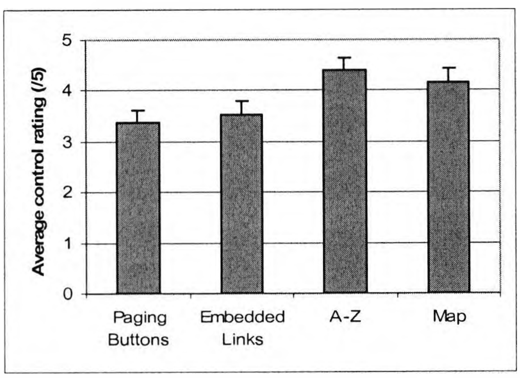

Figure 4.5 Average ratings on the control factor (+ 1 standard error) for each condition.

4.4.1.4. Knowledge Construction

The results of the analyses of the written transfer task are summarised in table 4.9 (see appendix 4.23 for further details of the output of these analyses).

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests ($p<0.05$)
Total transfer task mark (%)	paging buttons – 48.09; embedded links – 28.57; A-Z index – 35.71; map – 42.38.	Non-significant.	N/A.
A - Description of usability evaluation and its purpose (%)	paging buttons – 37.14; embedded links – 42.86; A-Z index – 42.86; map – 54.29.	Non-significant.	N/A.
B - Details of the evaluation techniques presented in the electronic text (%)	paging buttons – 62.86; embedded links – 45.71; A-Z index – 42.86; map – 60.00.	Non-significant.	N/A.
C - Understanding of how the usability evaluation techniques relate to each other (%)	paging buttons – 37.14; embedded links – 28.57; A-Z index – 17.14; map – 62.86.	Non-significant.	N/A.
D - Explanation of how each technique relates to the given usability evaluation setting (%)	paging buttons – 62.86; embedded links – 34.28; A-Z index – 54.29; map – 42.86.	Non-significant.	N/A.
E - Details of how the chosen technique will be employed (%)	paging buttons – 40.00; embedded links – 8.57; A-Z index – 31.43; map – 8.57. **(see figure 4.6).**	**Borderline significance** ($H(3,28)=7.393, p=0.060$)	None.
F - Argument quality (%)	paging buttons – 48.57; embedded links – 11.43; A-Z index – 25.71; map – 25.71. **(see figure 4.6).**	**Borderline significance** ($H(3,28)=7.704, p=0.053$)	paging buttons vs embedded links.

Table 4.9 Results of analyses for all aspects that the transfer tasks were marked on.

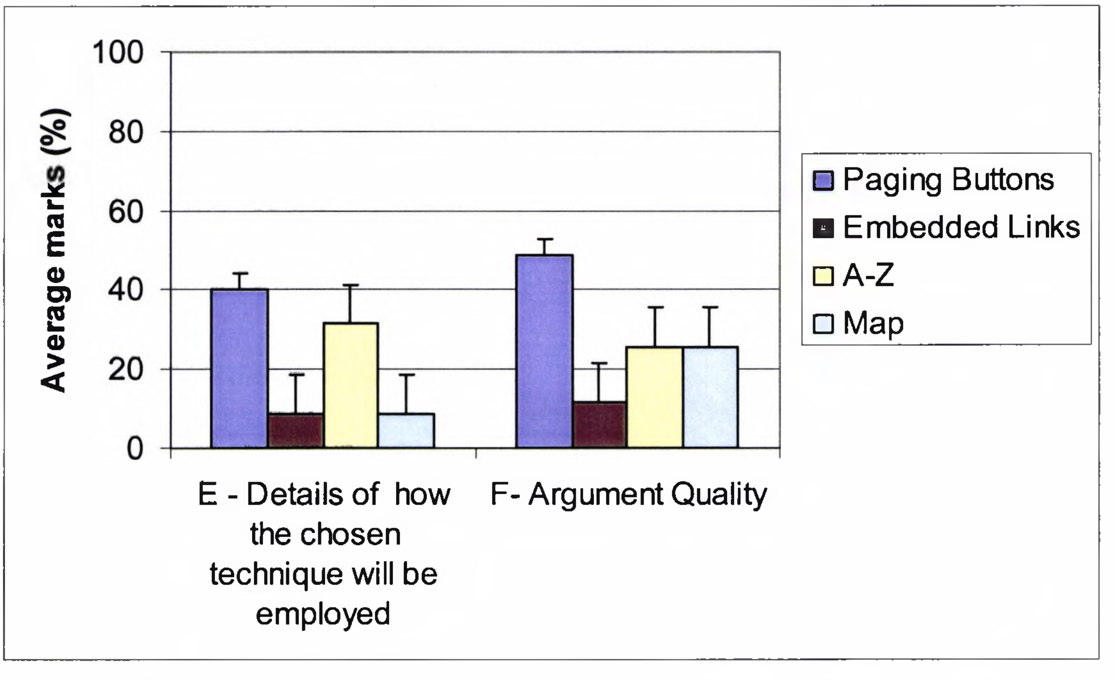

Figure 4.6. Average marks (+ 1 standard error) on aspects E and F of the transfer task for each condition.

The results of the analyses of the concept maps are summarised in table 4.10 (see appendix 4.24 for further details of the outputs of these analyses).

Analysis	Average for each condition	ANOVA	Significant post-hoc tests
Quantitative concept map mark	paging buttons – 36.57; embedded links – 21.43; A-Z index – 29.71; map – 33.43. **(see figure 4.7)**	**Parametric ANOVA significant** ($F(3,28)=4.004$, $p=0.019$)	Tukey: paging buttons vs embedded links.
Qualitative concept map mark (%)	paging buttons – 60.36; embedded links – 39.64; A-Z index – 40.00; map – 52.86. **(see figure 4.8)**	**Kruskal-Wallis approaching significance** ($H(3,28)=6.947$, $p=0.074$)	Siegal and Castellan: paging buttons vs A-Z index[4]

Table 4.10 Results of analyses for the quantitative and qualitative concept map marks.

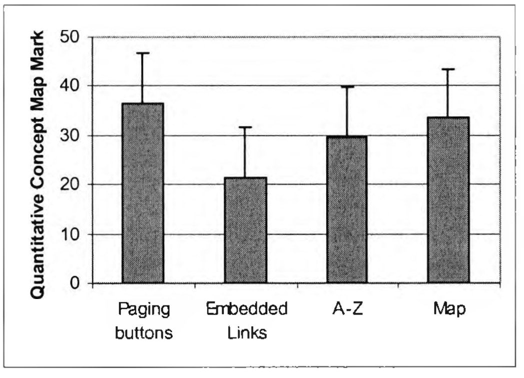

Figure 4.7 Average quantitative concept map marks (+1 standard error) for each condition.

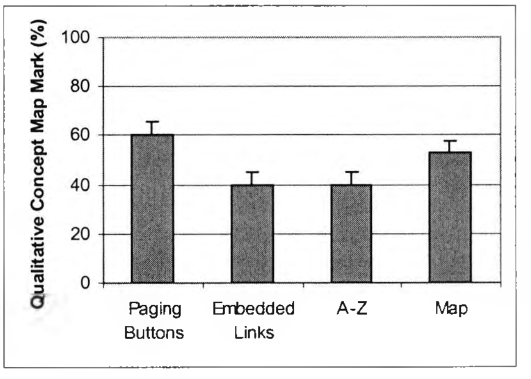

Figure 4.8 Average qualitative concept map marks (+1 standard error) for each condition.

4.4.2 Navigation and Usability Problems Measures

4.4.2.1. Navigation Behaviour

The results of the analyses for navigation behaviour are summarised in table 4.11 (see appendix 4.25 for further details of the outputs of these analyses).

[4] The fact that only paging buttons vs A-Z came up as significantly different on the post-hoc tests, when paging buttons vs embedded links did not, appeared to be erroneous since the difference in the average marks between paging buttons vs embedded links was actually greater than for paging buttons vs A-Z condition. However, this calculation has been checked and the reason for this result is the fact that the A-Z condition had a lower mean rank that the embedded links condition (see appendix 4.24), probably due to tied ranks, and this affected the calculation of the post-hoc test statistic.

Analysis	Average for each condition	ANOVA	Significant post-hoc tests
No. of operations	paging buttons – 108.00; embedded links – 117.43; A-Z index – 50.43; map – 61.00. **(see figure 4.9)**	**Parametric ANOVA significant** ($F(3,28)=3.285$, $p=0.038$)	Tukey: embedded links vs A-Z *approaching significance* (p=0.074).
No. of different pages visited (out of 23)	paging buttons – 23.00; embedded links – 20.43; A-Z index – 21.14; map – 22.71. **(see figure 4.10)**	**Kruskal-Wallis significant** ($H(3,28)=10.361$, $p=0.016$)	Siegal and Castellan: paging buttons vs embedded links *approaching significance* (p<0.075).

Table 4.11 Results of analyses for post-hoc navigation measures.

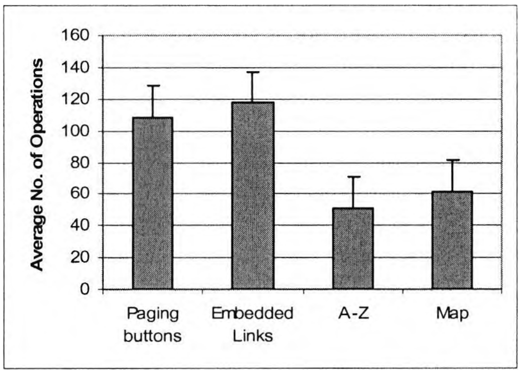

Figure 4.9 Average total no. of operations (+1 standard error) for each condition.

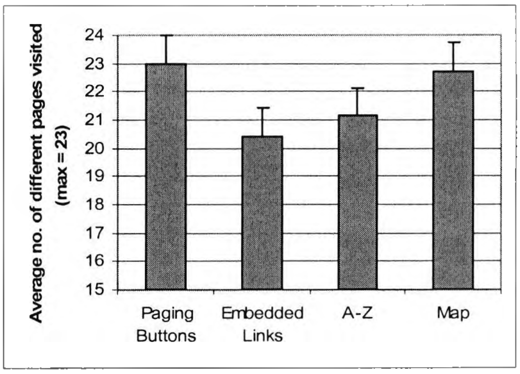

Figure 4.10 Average number of different pages visited (+1 standard error) for each condition.

4.4.2.2. Usability Problems

A total of 353 problem instances were identified from the final coding of the think-aloud transcripts for all participants in experiment 1. The results of analyses for instances of usability problems, unique usability problems and total problem severity are summarised in table 4.12 (see appendix 4.26 for further details of the outputs of these analyses).

Analysis	Average per participant for each condition	Kruskal Wallis ANOVA
Problem Instances	paging buttons – 13.14; embedded links – 10.29; A-Z – 16.29; map – 10.71.	Non-significant.
Unique Problems	paging buttons – 10.29; embedded links – 9.14; A-Z – 14.00; map – 9.14.	Non-significant.
Total Problem Severity	paging buttons – 23.57; embedded links – 20.43; A-Z – 30.14; map – 19.43.	Non-significant.

Table 4.12 Results of analyses performed on problem instances, unique problems and total problem severity.

Table 4.13 shows how the average number of unique usability problems per participant was distributed across categories for each condition, as well as the severity of problems within each category (for a full list of the problems that fell under each category for each condition see appendix 4.27). Figure 4.11 graphically represents this information.

		Paging Buttons	Embedded Links	A-Z	Map
General Confusion	Cosmetic	-	-	-	-
	Minor	-	0.29	0.29	0.29
	Major	-	-	-	-
	Catastrophe	-	-	-	-
	Total	-	**0.29**	**0.29**	**0.29**
Hardware	Cosmetic	0.29	-	0.14	-
	Minor	0.57	-	-	-
	Major	0.14	-	-	-
	Catastrophe	-	-	-	-
	Total	**1.00**	-	**0.14**	-
Text Content	Cosmetic	-	-	-	-
	Minor	0.14	0.57	1.29	0.14
	Major	-	-	-	-
	Catastrophe	-	-	-	-
	Total	**0.14**	**0.57**	**1.29**	**0.14**
Text Presentation	Cosmetic	-	-	0.29	0.14
	Minor	0.43	-	0.29	0.43
	Major	0.29	-	-	-
	Catastrophe	-	-	-	-
	Total	**0.71**	-	**0.57**	**0.57**
Using Aggregate Navigation Aid	Cosmetic	-	-	0.14	0.29
	Minor	-	-	2.00	3.43
	Major	-	-	0.00	0.14
	Catastrophe	-	-	0.00	0.00
	Total	-	-	**2.14**	**3.86**
Navigation Predicting	Cosmetic	-	-	-	-
	Minor	-	0.57	-	-
	Major	-	0.14	-	-
	Catastrophe	-	-	-	-
	Total	-	**0.71**	-	-
Navigation Disorientation	Cosmetic	-	-	-	-
	Minor	-	0.86	-	-
	Major	-	-	-	-
	Catastrophe	-	-	-	-
	Total	-	**0.86**	-	-
Navigation Text Structure	Cosmetic	-	-	0.14	-
	Minor	1.00	-	2.14	0.71
	Major	1.14	-	0.43	0.29
	Catastrophe	-	-	-	-
	Total	**2.14**	-	**2.71**	**1.00**
Navigation Efficiency	Cosmetic	-	-	-	-
	Minor	1.71	2.14	1.57	1.29
	Major	0.43	0.43	0.43	0.43
	Catastrophe	-	-	-	-
	Total	**2.14**	**2.57**	**2.00**	**1.71**
Understanding Text	Cosmetic	0.43	0.57	-	-
	Minor	2.00	2.43	2.57	0.86
	Major	1.71	0.86	2.29	0.71
	Catastrophe	-	-	-	-
	Total	**4.14**	**3.86**	**4.86**	**1.57**
Other	Cosmetic	-	-	-	-

	Minor	-	0.29	-	-
	Major	-	-	-	-
	Catastrophe	-	-	-	-
	Total	**-**	**0.29**	**-**	**-**

Table 4.13. Average number of unique problems per participant in each category for each condition and their severity.

The key findings for each condition have been identified from figure 4.11 and will be discussed in turn. For the paging buttons condition problems mainly fell into the "Understanding Text" category, and over one third of these were major problems. Also in the paging buttons condition more problems were experienced in the hardware category than any other condition. However, another notable result was that no problems were experienced in the "General Confusion", "Navigation Predicting", "Navigation Disorientation" and "Other" categories.

For the embedded links condition, again, problems mainly fell into the "Understanding Text" category and the majority of these were minor problems. Problems in the "Navigation Disorientation", "Navigation Predicting" and "Other" categories were unique to the embedded links condition and did not occur in any of the other conditions. Problems in these categories were generally minor. It may also be noted that participants in the embedded links condition did not experience any problems in the "Navigation Text Structure", "Text Presentation" and "Hardware" categories.

For the A-Z condition, similarly, problems mainly fell into the "Understanding Text" category and nearly half of these were major problems. It may also be noted that participants in the A-Z condition did not experience problems in the "Navigation Disorientation", "Navigation Predicting" and "Other" categories.

Finally, for the map condition, problems mainly fell under the "Using Aggregate Navigation Aid" category compared to all the other categories and were specific problems associated with using the map to navigate. Compared to the other conditions the map condition led to the lowest number of problems in the category "Understanding Text". It should also be noted for the map condition there were no problems in the "Hardware", "Navigation Predicting", "Navigation Disorientation" and "Other" categories.

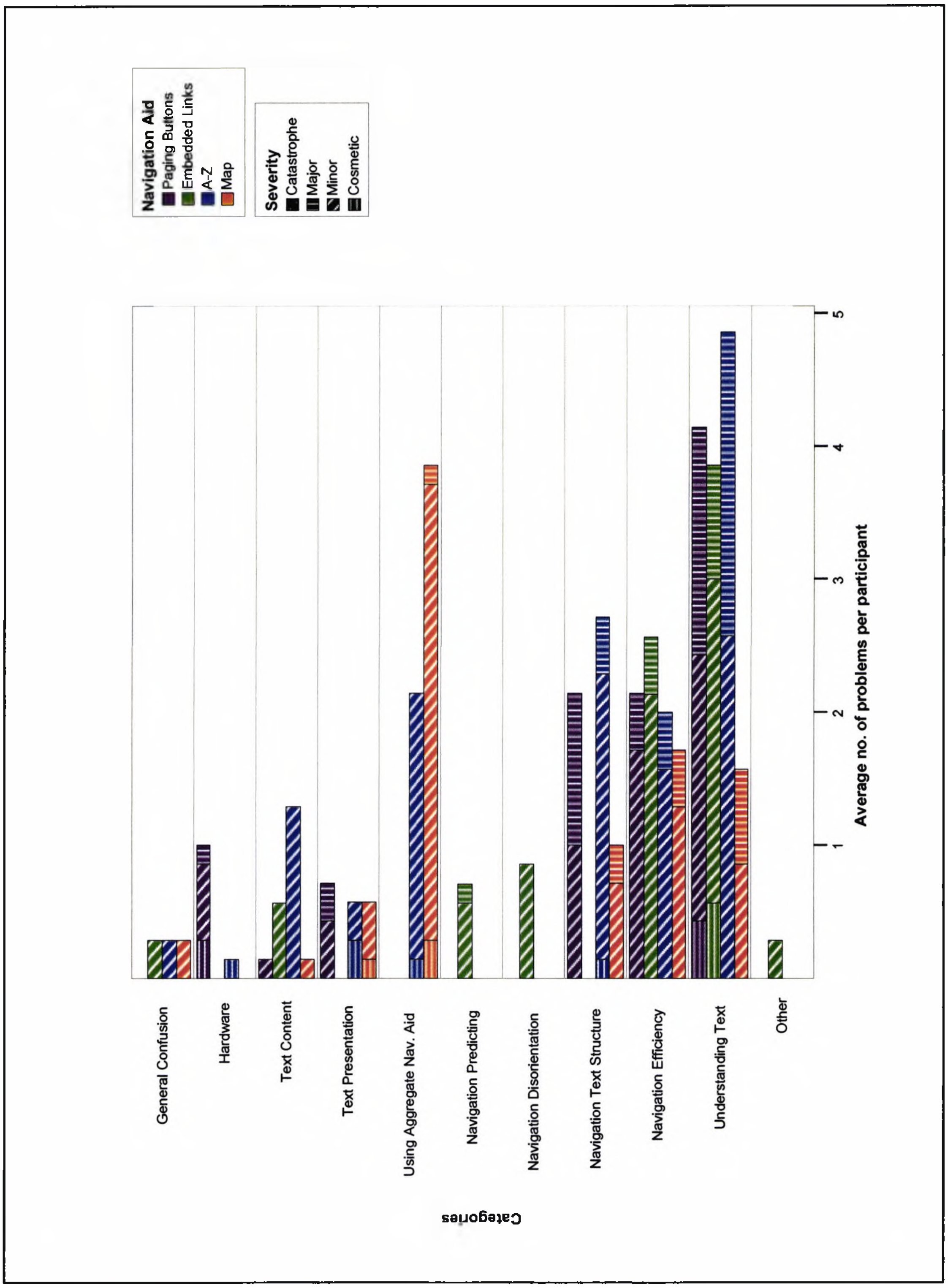

Figure 4.11 Average number of problems per participant in each category for each condition and their severity.

4.5 Discussion

Based on the framework of constructivism in chapter 3, it was hypothesised that learners who used navigation aids that offer higher levels of navigational freedom would show higher levels of cognitive engagement, would feel higher levels of ownership and would develop higher quality knowledge constructions than those who used navigation aids with lower navigational freedom. Overall, the results of this experiment indicate that the level of navigational freedom offered by a navigation aid does impact upon some of the aspects of learning investigated here, although this was not always as predicted. The experimental findings are summarised and potential explanations are discussed in this section. Finally, the implications of these findings are identified.

4.5.1 Results Summary and Explanation for Findings

The results for each of the learning measures taken to test the experimental hypotheses are discussed in turn. Potential explanations for any differences between conditions are considered in light of the post-hoc analyses of navigation behaviour and usability problems, as well as in terms of cognitive load theory. In addition, findings are also discussed in relation to previous research.

4.5.1.1. Cognitive Engagement

The main finding for the cognitive engagement measures was:

- ⇨ There were no significant differences between conditions for the total cognitive engagement scores or for any of the individual cognitive engagement activities.

This suggests that navigation aids offering different levels of navigational freedom did not have significant effects on participants' level of cognitive engagement as measured in this experiment.

4.5.1.2. Ownership

From the responses to the ownership questionnaire, it was found that:

- ⇨ The level of navigational freedom offered by a navigation aid had significant impact upon feelings of control for learning with electronic texts. In particular, A-Zs and maps led to significantly higher feelings of control than paging buttons and embedded links.
- ⇨ There were no significant effects of the level of navigational freedom offered by a navigation aid on overall ownership, or on the other component feelings of responsibility and value.

This suggests that the higher level of navigational freedom offered by the A-Z and the map encourages higher feelings of control in the learner than the lower levels of navigational freedom offered by the paging buttons and embedded links.

The navigation performance measures were examined for potential explanations for the difference in feelings of control between conditions. This revealed that participants in the paging buttons and embedded links conditions performed a notably higher number of operations than those in the A-Z and map conditions. This is the inverse of the pattern that was found for feelings of control. Hence, it can be seen that a lower number of operations occurred in the same conditions that were conducive to higher feelings of control. This highlights that differences in the number of operations performed by participants may have had some relationship to feelings of control. However, there appeared to be no relationship between the pattern of results for the number of different pages visited and the pattern of results for feelings of control.

The usability problems were then examined for potential explanations for the finding on control. However, no significant differences were found between conditions for the number of instances, number of unique problems, and total severity of problems experienced by participants. Consequently, these measures could not provide any explanation for the finding on control. The types of usability problems experienced by participants in the paging buttons and embedded links conditions were also compared to the types of problems experienced by participants in the A-Z and map conditions. However, this provided did not provide any clear explanation for the finding on control.

4.5.1.3. Knowledge Constructions

Contrary to H_3, the results of this experiment revealed that:

- ⇨ Paging buttons (lower navigational freedom) led to the highest quality knowledge construction of all the navigation aids investigated here, according to the measures employed. Participants who used paging buttons gave a significantly more coherent argument structure in the written transfer task than participants who used embedded links (medium navigational freedom), and were better able to give details of a selected usability evaluation technique than participants in other conditions. They produced higher quality hand-drawn concept maps, as shown by the qualitative measures, compared to participants who used the A-Z index and those who used embedded links. In addition, they also produced significantly more detailed concept maps, compared to participants who used embedded links as shown by the quantitative measures.
- ⇨ Participants in the embedded links condition showed the lowest performance on these knowledge construction measures (aspects E and F of the transfer task and the quantitative and qualitative concept map marks).
- ⇨ The performance of the participants in the A-Z and map conditions (both high navigational freedom), on the other hand, generally fell between these extremes,

and no differences were found between A-Zs and maps in terms of the knowledge construction measures.

Three potential explanations for the poor performance on the knowledge construction measures of participants in the embedded links condition are discussed here. These explanations are described in terms of navigation behaviour, usability problems and cognitive load theory. It should be noted that the explanations are not mutually exclusive.

Firstly, poor performance on the knowledge construction measures may be accounted for by the finding that participants who navigated using the embedded links on average did not visit all the pages in the electronic text. In fact, participants in the embedded links condition visited the lowest number of different pages in the electronic text compared to the other conditions, and this difference was particularly marked between the embedded links condition and the paging buttons condition. This suggests that participants in the embedded links condition did not take in all of the information in the electronic text.

A second potential explanation is described here in terms of the usability problems experienced by participants. The instances of usability problems, unique usability problems and the total severity of usability problems identified from participants' verbal protocols were examined. No significant differences were found between conditions on any aspects of the usability problems. Nevertheless, an explanation for the poor performance of the participants in the embedded links condition on the knowledge construction measures can be given in terms of the types of usability problems that were unique to embedded links. These consisted of general problems associated with using the electronic texts to choose a usability evaluation technique for the experimental task, problems making predictions about navigation of the electronic text (i.e. predicting where links will taken them), and problems concerning feelings of disorientation when navigating the text including problems getting an overview of the text. These problems may have had negative effects on knowledge construction.

A third potential explanation for the finding that embedded links had detrimental effects on knowledge construction, particularly as compared to paging buttons, can be given in terms of cognitive load. As discussed in chapter 2, "cognitive load" is the burden that a particular task imposes on the cognitive system (Sweller, 1988). According to this theory, the limited capacity of working memory has important implications for the development of knowledge (Chandler and Sweller, 1996). The two main types of cognitive load are intrinsic cognitive load, determined by the demands of the task, and extraneous cognitive load, as determined by the format of information.

In this experiment, intrinsic cognitive load was already at a challenging level because the participants were unfamiliar with the content of the electronic text. This means that any extraneous cognitive load would have infringed on the working memory capacity available for knowledge construction. It can be argued that the embedded links condition put extraneous cognitive load on participants, thereby affecting their performance on the transfer and concept-mapping tasks. When using the embedded links, extraneous cognitive load may have arisen as learners put effort into developing a mental overview of the text, working out where they were, where they had been, and where they wanted to go. This ties in with the usability problems of disorientation discussed above. In the paging buttons condition, however, the navigational decisions were less complicated because the navigation sequence was already determined. The findings of this experiment indicate that the lower navigational freedom in the paging buttons condition was beneficial and that participants were able to focus their attention on understanding the content of the electronic text.

However, there may be some contention over interpreting the data from the concept mapping tasks and whether this really reflected participants' conceptual knowledge of the electronic text. For example, for the participants in the map condition, the concept mapping task may not have simply assessed the participants' conceptual knowledge. Instead their performance on the task may have been influenced by participants simply reproducing the map navigation aid. This issue will be discussed in more detail in chapter 7.

The fact that the A-Z and map conditions, which offered higher navigational freedom, did not significantly affect participants' knowledge construction, as compared to the lower navigational freedom in the paging buttons and embedded links conditions, indicates that the overviews offered by the A-Z and map gave no significant benefits over the paging buttons and embedded links conditions.

4.5.1.4. Relation to Previous Research

Comparing the results with previous research on navigation aids and learning discussed in chapter 2, it is particularly noticeable that the experimental results conflict with those presented by Dee-Lucas and Larkin (1995). They found that A-Z and map overviews were more beneficial to learning than paging buttons. In contrast, in this experiment, paging buttons were most beneficial to the knowledge construction measures. One explanation is that the findings differ due to variations in the particular versions of the navigation aids and the measures of learning used in the experiments. In Dee-Lucas and Larkin (1995), both the A-Z index and the map overviews were *not* constantly available while the learners read the electronic text and learners had to alternate between the overviews and the text content. In the present experiment, however, in the A-Z and map conditions the navigation aids were presented in a left-hand frame at the same time as the content of the page, presented in a right-hand frame. Learners could simply use the navigation aids to click on the page they wished to visit without having to alternate between the navigation aid and the text content. This discrepancy may account for the differences in the findings presented here. Perhaps the fact that the learners in Dee-Lucas and Larkin's (1995) study had to constantly return to the overview meant that the information in the overview was reinforced and their participants may have been more likely to take note of page titles. Memory for page titles was one of their measures of learning.

Finally, in terms of research on learner control in electronic texts, the present findings indicate that higher learner control, as offered by navigation aids with higher navigational freedom, does not offer benefits to learning over navigation aids that offer lower navigational freedom. This supports the findings on learner control of McGrath (1992) and Niederhauser et al. (2000). However, from responses to the ownership questionnaire we also know that navigation aids that offer higher navigational freedom also lead to higher feelings of control, so learners *do* recognise the control they are given through these navigation aids.

4.5.2 Implications of Experimental Findings

Considering the scope of this experiment, in terms of the type of texts, type of tasks, characteristics of the participants, and the experimental context, five key implications for the use of navigation aids in educational electronic texts have been identified. These will be discussed in turn.

1. In terms of cognitive engagement, the level of navigational freedom offered by a navigation aid has no significant impact. As such, designers of educational electronic texts wanting to encourage cognitive engagement during the use of these texts should look to factors in design other than the level of navigational freedom offered by navigation aids.
2. Navigation aids that offer higher navigational freedom lead to higher feelings of control, but not higher overall ownership or higher feelings of responsibility and value. Consequently, this suggests that designers of educational electronic texts

should not simply look at navigational freedom to encourage feelings of ownership for learning. They should also address issues related to encouraging the learner's feelings of responsibility and value. It can be anticipated that aspects of the learning environment that might influence these feelings include the relevancy of the task to the learner and the learner's involvement in decision making about the task.

3. Paging buttons are particularly beneficial in terms of the quality of knowledge construction about an electronic text and learners appear to benefit from this lower navigational freedom. As such, designers should consider employing these as navigation aids in educational electronic texts.
4. The use of embedded links appears to have detrimental effects on the quality of knowledge construction when learning with electronic texts. It has been argued that this is due to high extraneous cognitive load and disorientation problems. Accordingly, designers should exercise caution when employing these as navigation aids in educational electronic texts.
5. The use of navigation aids that offer higher navigational freedom, such as A-Z indexes and maps, has no effects on the quality of knowledge construction as compared to those with lower navigational freedom, such as paging buttons or embedded links. Therefore, designers should also look to other factors in the design of the electronic texts if they want to encourage the development of higher quality knowledge constructions.
6. Comparisons with the findings of previous research on the effects of navigation aids that provide an overview of the electronic text indicates that there are some differences in the findings. This highlights that the effects of navigation aids on learning are complex. Designers of educational electronic texts should be aware of this.

4.5.3 Conclusions

Overall, the findings from this experiment do not provide support for $H_1 - H_3$ developed from the framework of constructivism and navigation in chapter 3. Findings indicate that navigation aids that offer higher navigational freedom had little effect on cognitive engagement, ownership and knowledge construction. However, lower navigational freedom offered by paging buttons was found to be beneficial to some aspects of knowledge construction. Therefore, designers should not assume that navigation aids that offer higher navigational freedom will have benefits in terms of cognitive engagement, ownership and knowledge construction with electronic texts.

From these findings it also appears that higher navigational freedom may be too simplistic an interpretation of learner control. The next chapter presents an experimental investigation into the effects of another form of control over navigation in electronic texts: allowing learners to create their own navigation aids.

5 Experiment 2: Creating Navigation Aids in Educational Electronic Texts

This chapter presents experimental investigations into the effects on learning of creating vs using three types of navigation aids: a map, an alphabetical index and a contents list.

5.1 Introduction

In chapter 3, the importance of tools and signs was highlighted as a theme in constructivism and within this theme the articulation and externalisation of ideas through tools and signs was emphasised as an important factor in learning (e.g. Duffy and Cunningham, 1996; Vygotsky, 1978). Articulation has been shown to contribute to the development of new knowledge (Koschmann and LeBaron, 2002) both through summarization (Davis and Hult, 1997; King, 1992) and self-explanation (Aleven and Koedinger, 2002). The importance of learner control was also highlighted in the framework of constructivism and the last chapter looked at the effects of learner control through navigational freedom. This chapter presents an experimental investigation into the effects of allowing learners to articulate their ideas and exert control over their learning with an electronic text through creating their own navigation aids.

Creating navigation aids, such as maps, indices and contents lists, allows learners to articulate their ideas about the content of an electronic text. Through creating a navigation aid the learner also has the control to tailor the structure, content and layout of the navigation aid to their own needs and thus make decisions about how they will access materials and in what order.

The work in this chapter contributes towards thesis **objective 3**, *"To empirically test hypotheses that were motivated by the framework of constructivism and navigation"*. The following hypotheses were developed from the framework in order to investigate the effects of creating navigation aids on learning:

H_4 – *Learners who create their own navigation aids will show higher levels of cognitive engagement when using an educational electronic text than learners who use existing navigation aids.*

H_5 – *Learners who create their own navigation aids will feel higher levels of ownership for their learning with an educational electronic text than learners who use existing navigation aids.*

H_6 – *Learners who create their own navigation aids will develop higher quality knowledge about the content of an educational electronic text than learners who use existing navigation aids.*

This chapter describes a three-part experimental investigation designed to test H_4 – H_6 with three different types of navigation aids: a map, an A-Z index and a contents list. Three navigation aids were selected for investigation and a three part experiment was conducted in order to make the scope broader than focussing on just one type of navigation aid. These particular types of navigation aids were chosen since they represent typical navigation aids in educational electronic texts.

In part A of this experiment, the effects on learning of creating vs using maps are investigated. In part B, the effects on learning of creating vs using A-Z indices are investigated. Finally, in part C, the effects on learning of creating vs using contents lists are examined. It should be noted that this experiment does not aim to compare using maps, A-Z indices and contents lists explicitly, since previous research has addressed these issues (e.g. McDonald and Stevenson, 1999; Puntambekar and Stylianou, 2003). Nor does this experiment aim to explicitly compare the effects of creating maps, A-Z indices and contents lists.

Overall, the experimental procedures and measures are the same as those in experiment 1. Learners used an electronic text on usability evaluation with the facilities to create or use navigation aids and their learning was assessed in terms of cognitive engagement, ownership and knowledge construction. As mentioned earlier, some of the data analysis for experiments 1 and 2 was performed together, and this is described in more detail in chapter 4 and in section 5.3 of the present chapter. The method and results of each part of this experiment are presented. Finally to meet thesis **objective 4**, *"To distil the findings of the empirical investigations into a set of implications to inform designers and researchers of educational electronic texts"*, implications of the findings are discussed.

5.2 Method

H_4 – H_6 were tested with three different types of navigation aids in three sub-experiments. Learners were given the facilities to create or use a map, an A-Z index or a contents list. The procedures and measures used in all three sub-experiments were the same as in experiment 1. In part A, participants used either a map, the facilities to create a map, or embedded links as navigation aids in an electronic text. Similarly, in part B, participants used either an A-Z index, the facilities to create an A-Z index, or embedded links as navigation aids in an electronic text. In part C, participants used either a contents list, the facilities to create a contents list, or embedded links as navigation aids in an electronic text. Embedded links were included here as a comparison condition since they formed a baseline for each of the using and creating conditions in parts A, B and C.

In all three sub-experiments, participants were tested beforehand to determine their prior knowledge of the subject described in the electronic text. Whilst using the navigation aids to explore the electronic text, participants were given a task to use the information in the text to solve a problem. They were asked to think aloud so that their level of cognitive engagement could be established from their verbalisations and their interactions with the electronic text were recorded both on video and in computer log files. Afterwards, their feelings of ownership for learning were measured using an ownership questionnaire and their knowledge of the text was assessed in two ways: they were asked to undertake a written "transfer" task and to hand draw a conceptual map of the electronic text. This section describes in detail the participants, the procedures and the measures used in parts A-C of this experiment.

5.2.1 Part A – Creating vs Using Maps

5.2.1.1. Participants

Fourteen undergraduates on an introductory HCI course in the spring term 2003 at City University took part in part A of the experiment (see table 5.1). As with participants in experiment 1, all had attended an introductory HCI lecture, but had not yet attended a lecture on usability evaluation (the topic presented in the electronic text) as part of their HCI course.

Age Range		Gender		Undergraduate/ Postgraduate		Computer Experience *		WWW Experience *		WWW Use	
18-29yrs.	11	Female	6	Undergrad.	6	< 1 yr.	0	< 1 yr.	0	Daily	13
30-39yrs.	0	Male	8	Postgrad.	8	1-3 yrs.	1	1-3 yrs.	3	Weekly	0
40-49yrs.	3	-	-	-	-	4-5 yrs.	3	4-5 yrs.	6	Monthly	0
50+ yrs.	0	-	-	-	-	5+ yrs.	9	5+ yrs.	4	Rarely	0

Table 5.1. The number of participants in each demographic category, and the number in each category for computer and web experience.

* One participant did not answer this question.

5.2.1.2. Equipment and Materials

As in experiment 1, participants used a DELL PC running an Intel Xeon processor and 1GB RAM with a 19" monitor, keyboard and mouse. They also used the Nestor Navigator browser to access and navigate the electronic text on usability evaluation. Participants' verbalisations and interactions as they used the electronic text were recorded on video camera. In addition, log files in Nestor Navigator recorded the navigation aid used (i.e. whether the navigation was by the map, links or back button), the page visited and the time the page was visited.

5.2.1.3. Design and Procedure

A between-subjects design was employed and participants were randomly assigned to experimental conditions. The independent variable was the type of navigation provided and the three experimental conditions were:

1. using a map (+ embedded links)
2. creating a map (+ embedded links)
3. embedded links

The fourteen participants in part A were randomly assigned to either the using map or creating map conditions, seven in each condition. The third condition (embedded links) comprised of the data collected from the seven embedded links participants in experiment 1.

In the first condition (using a map) participants could access the electronic text through a map of page titles, which showed all twenty-three pages in the electronic text, displayed in a left-hand window and/or through embedded links within the text and/or by using a back button (see figure 5.1). In the second condition (creating a map) participants initially could only access the text through embedded links within the text and/or by using a back button. Each time the participant visited a new page, the page title and the link that was followed were added to a map in the left-hand window. This map could then be used to navigate the text. In addition, participants could re-arrange the elements of the map, delete pages and add conceptual links to the map (i.e. links that didn't represent an actual navigation link in the electronic text) according to their own preferences, thus creating their own customised map (see figure 5.2). In the creating map condition, the node for the page that was currently being displayed was shown in red (rather than the standard blue). It should be noted that in the using map condition the map gave no indication of which page was currently being displayed (this is a feature of Nestor Navigator). It should also be noted that Nestor Navigator provided several other functions for map creation, such as adding conceptual areas and annotations, but that the participants were asked to only use the ones listed here.

As described in chapter 4, in the third condition (embedded links) participants could either navigate by embedded links or a back button. This condition was included here as a comparison condition because the embedded links and back button form a baseline for both the using map and creating map conditions. The use of the data from experiment 1 is valid because the procedures and measures were the same in experiments 1 and 2.

The experimental procedure was the same as in experiment 1 (see section 4.2.3 in chapter 4 for more details), except that when the participants used the electronic texts in part 3 of the procedure, participants in the "creating map" condition were also asked to create their map of the electronic text. See appendices 4.2 – 4.5 for the experimental script, the pre-test and demographic questionnaire, training instructions, and the instructions for the task as they used the electronic text. See appendices 4.7 – 4.9 for the ownership questionnaire, written transfer task instructions and the concept mapping task instructions.

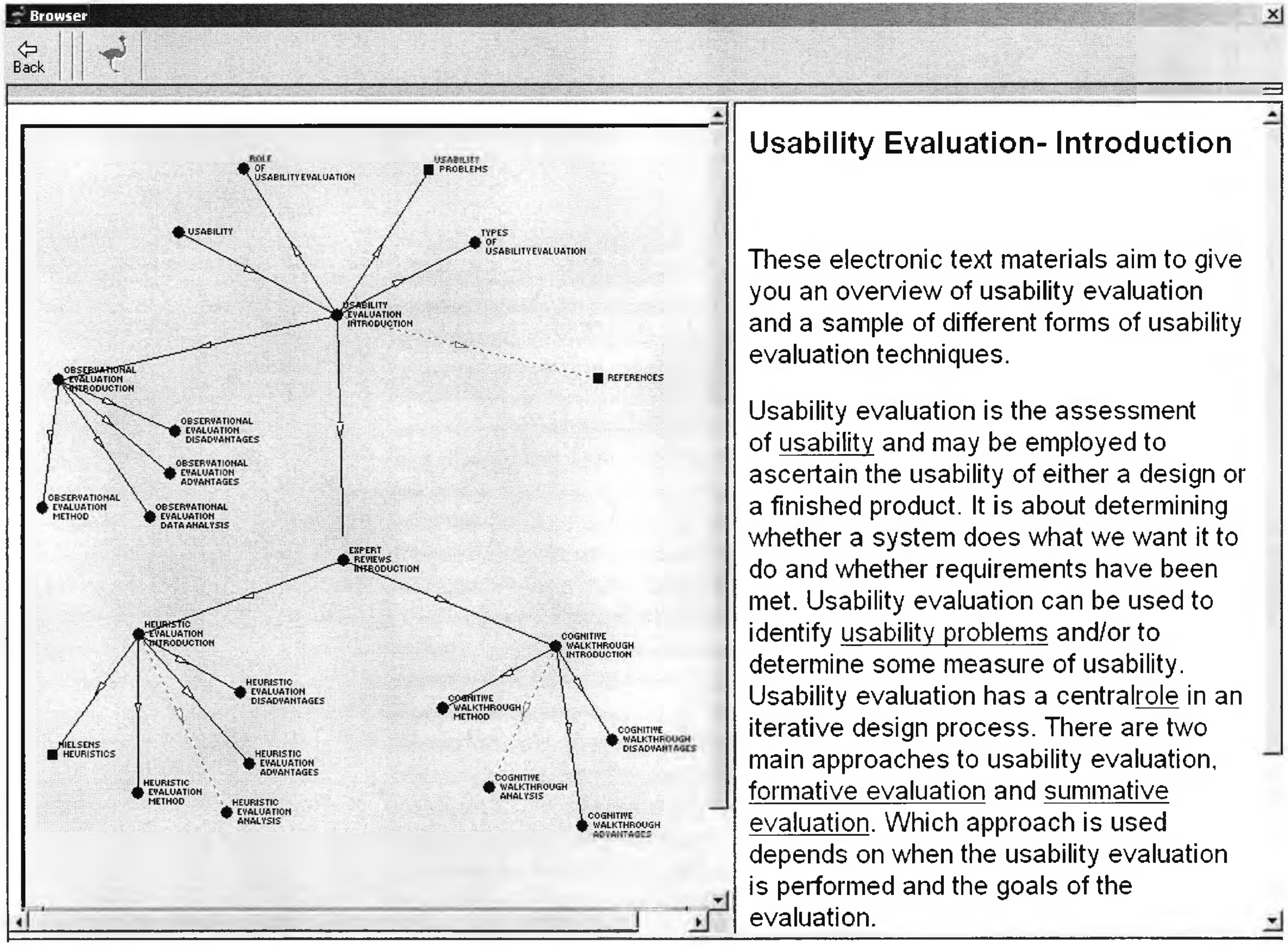

Figure 5.1. The using map condition.

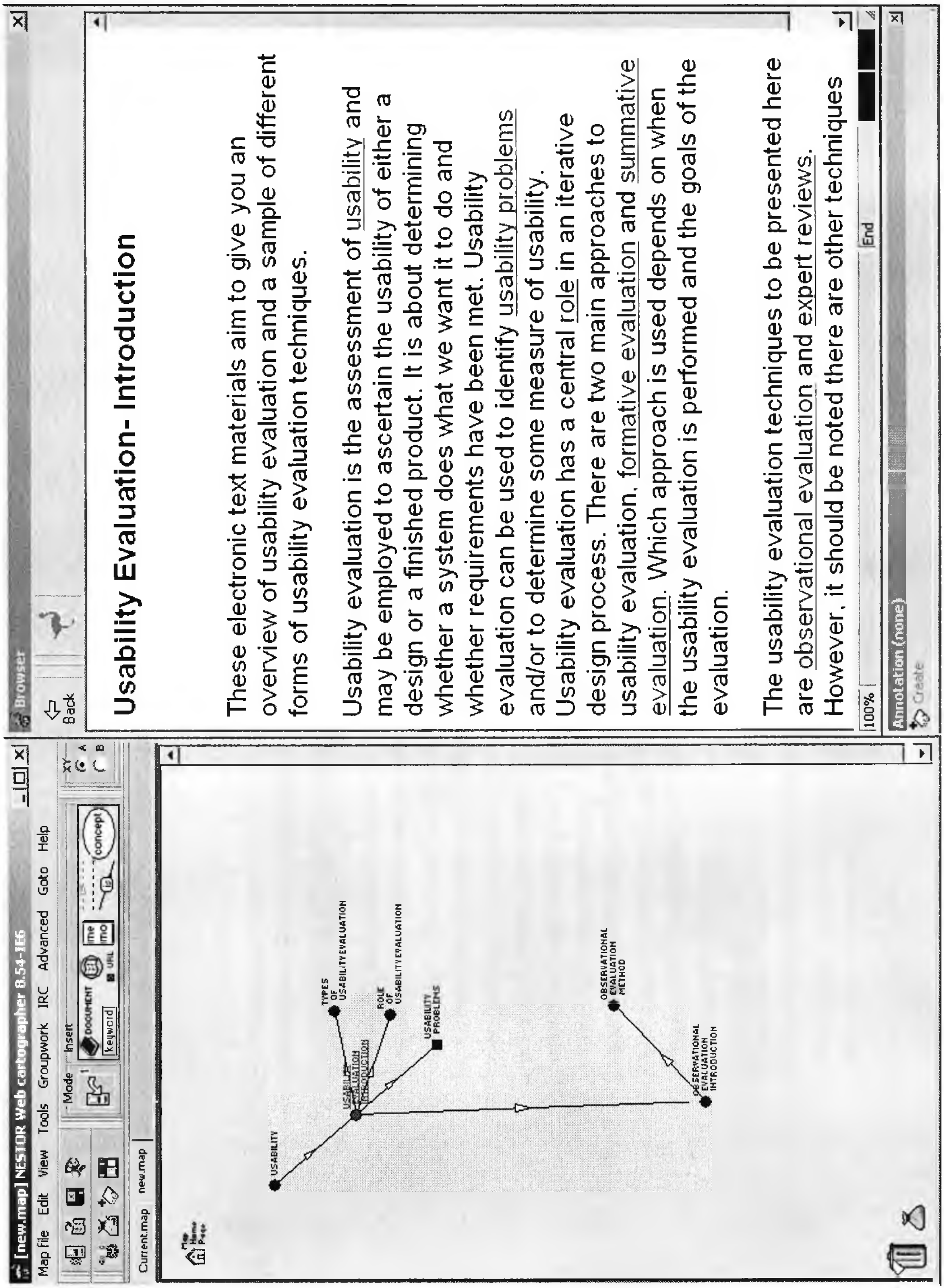

Figure 5.2. The creating map condition.

Learning Measures

As in experiment 1, the pre-test (see appendix 4.3) was administered to participants as a control measure to determine whether they all had the same level of background knowledge of the content of the electronic text. This consisted of seven questions testing their knowledge of the topic presented in the electronic text.

Three dependent variables were employed to test $H_4 - H_6$: cognitive engagement (as measured by participants' think-aloud verbalisations whilst using the electronic text), feelings of ownership for learning (as measured by an ownership questionnaire; see appendix 4.7), and knowledge construction (as measured by performance on a transfer task and a concept-mapping task see appendices 4.8 and 4.9). These were the same as those in experiment 1 and their details were described in experiment 1 in chapter 4. Details of how this data was analysed are described in chapter 4 and the results are described in section 5.3.1.1.

Navigation and Usability Problem Measures

As in experiment 1, navigation behaviour was assessed through post-hoc analyses of the log files collected in the Nestor Navigator browser. The purpose of analysing this data was to provide explanation for the results of the learning measures taken to test the experimental hypotheses. Also, as in experiment 1, the transcripts of participants' verbalisations were used to assess the usability problems experienced. Details of how this data was analysed were described in chapter 4, and additional analyses and the results are described in section 5.3.1.2.

5.2.2 Part B – Creating vs Using A-Z Indices

5.2.2.1. Participants

Fourteen undergraduates and postgraduates on an introductory HCI course in the spring term 2003 at City University took part in part B (see table 5.2). These were different people to those who participated in part A. As with participants in experiment 1, and those in part A of this experiment, all had attended an introductory HCI lecture, but had not yet attended a lecture on usability evaluation (the topic presented in the electronic text).

Age Range		Gender		Undergraduate/ Postgraduate		Computer Experience		WWW Experience		WWW Use	
18-29yrs.	12	**Female**	8	**Undergrad.**	5	**< 1 yr.**	0	**< 1 yr.**	0	**Daily**	12
30-39yrs.	2	**Male**	6	**Postgrad.**	9	**1-3 yrs.**	3	**1-3 yrs.**	3	**Weekly**	2
40-49yrs.	0	-	-	-	-	**4-5 yrs.**	4	**4-5 yrs.**	4	**Monthly**	0
50+ yrs.	0	-	-	-	-	**5+ yrs.**	7	**5+ yrs.**	7	**Rarely**	0

Table 5.2. The number of participants in each demographic category, and the number in each category for computer and web experience and web use for part B.

5.2.2.2. Equipment and Materials

As in experiment 1 and part A of this experiment, participants used a DELL PC running an Intel Xeon processor and 1GB RAM with a 19" monitor, keyboard and mouse. They also used the Nestor Navigator browser to access and navigate the same electronic text on usability evaluation. Participants' verbalisations and interactions as they used the electronic text were recorded on a VHS with mixed screen capture and their faces were recorded in a box in the bottom left hand corner of the video screen. In addition log files in Nestor Navigator recorded the navigation aid used (i.e. whether the navigation was by the A-Z, links or back button), the page visited and the time the page was visited.

5.2.2.3. Design and Procedure

A between-subjects design was employed and participants were randomly assigned to experimental conditions. The independent variable was the type of navigation provided and the three experimental conditions were:

1. using an A-Z index (+ embedded links)
2. creating an A-Z index (+ embedded links)
3. embedded links

As in part A, the fourteen new participants in this experiment were randomly assigned to either the using A-Z or creating A-Z conditions, seven in each condition. Again, as in part A, the third condition (embedded links) comprised of data collected from the seven embedded links participants in experiment 1.

In the first condition (using an A-Z index), participants could access the electronic text through an interactive alphabetical index of page titles that showed all twenty-three pages in the electronic texts in the left-hand frame and/or through embedded links within the text and/or by using a back button (see figure 5.3). In the second condition (creating an A-Z index), participants could only access pages initially through embedded links within the text and/or by using a back button. Each time the participant visited a page the page title was represented in the left-hand window. These page titles could then be used to navigate, and participants could re-arrange the page titles into alphabetical order (see figure 5.4). In the creating A-Z condition, the node for the page that was currently being displayed was shown in red (rather than the standard blue). It should be noted that in the using A-Z condition the map gave no indication of which page was currently being displayed (this is a feature of Nestor Navigator).

The experimental procedure was the same as in experiment 1 (see section 4.2.3 in chapter 4 for more details), and part A of this experiment, except that in part 3 of the procedure participants in the "creating A-Z index" condition created their A-Z. See appendices 4.2 – 4.5 for the experimental script, the pre-test and demographic questionnaire, training instructions, and the instructions for the task as participants used the electronic text. See appendices 4.7 – 4.9 for the ownership questionnaire, written transfer task instructions and the concept mapping task instructions.

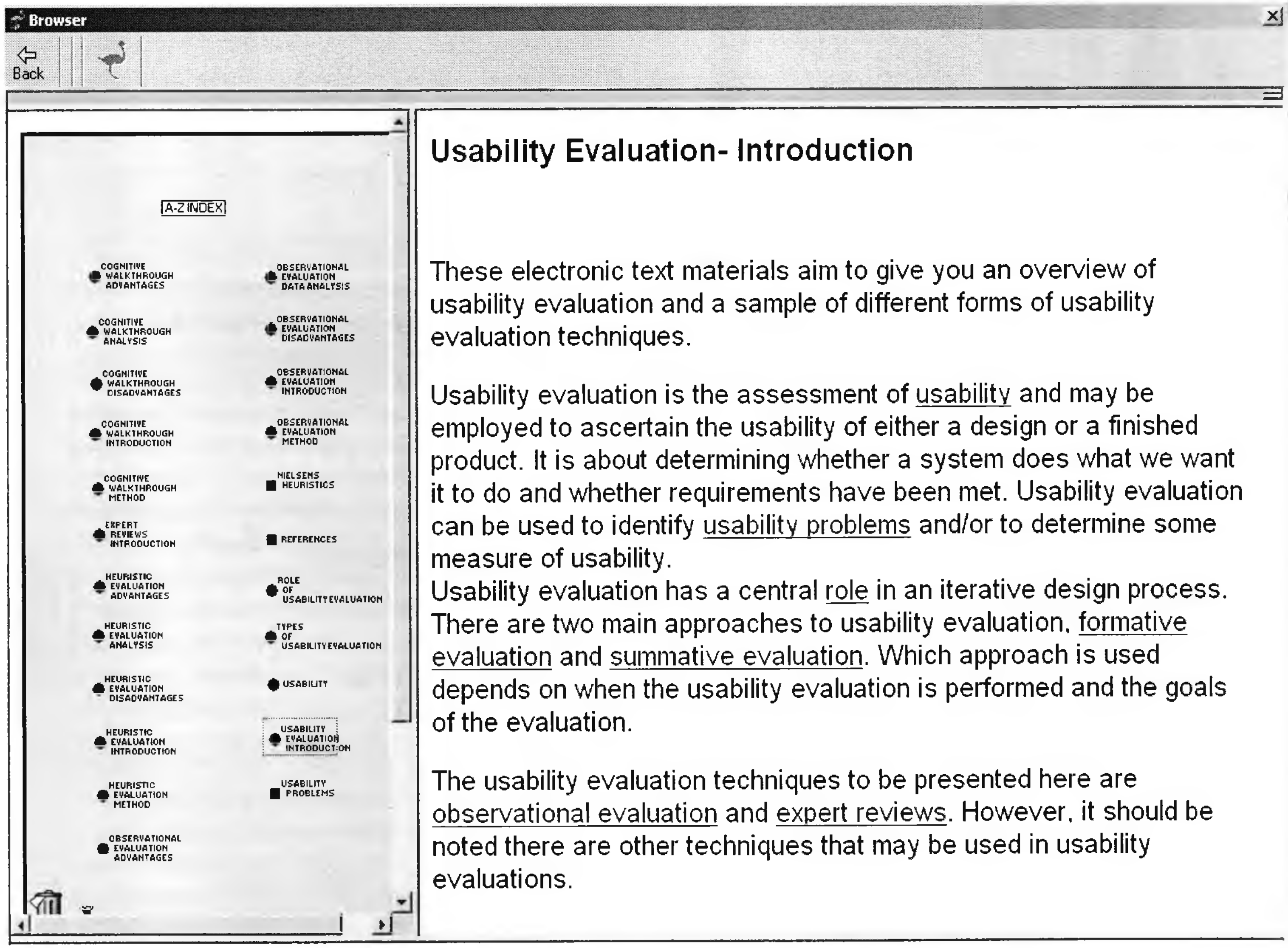

Figure 5.3. The using A-Z condition.

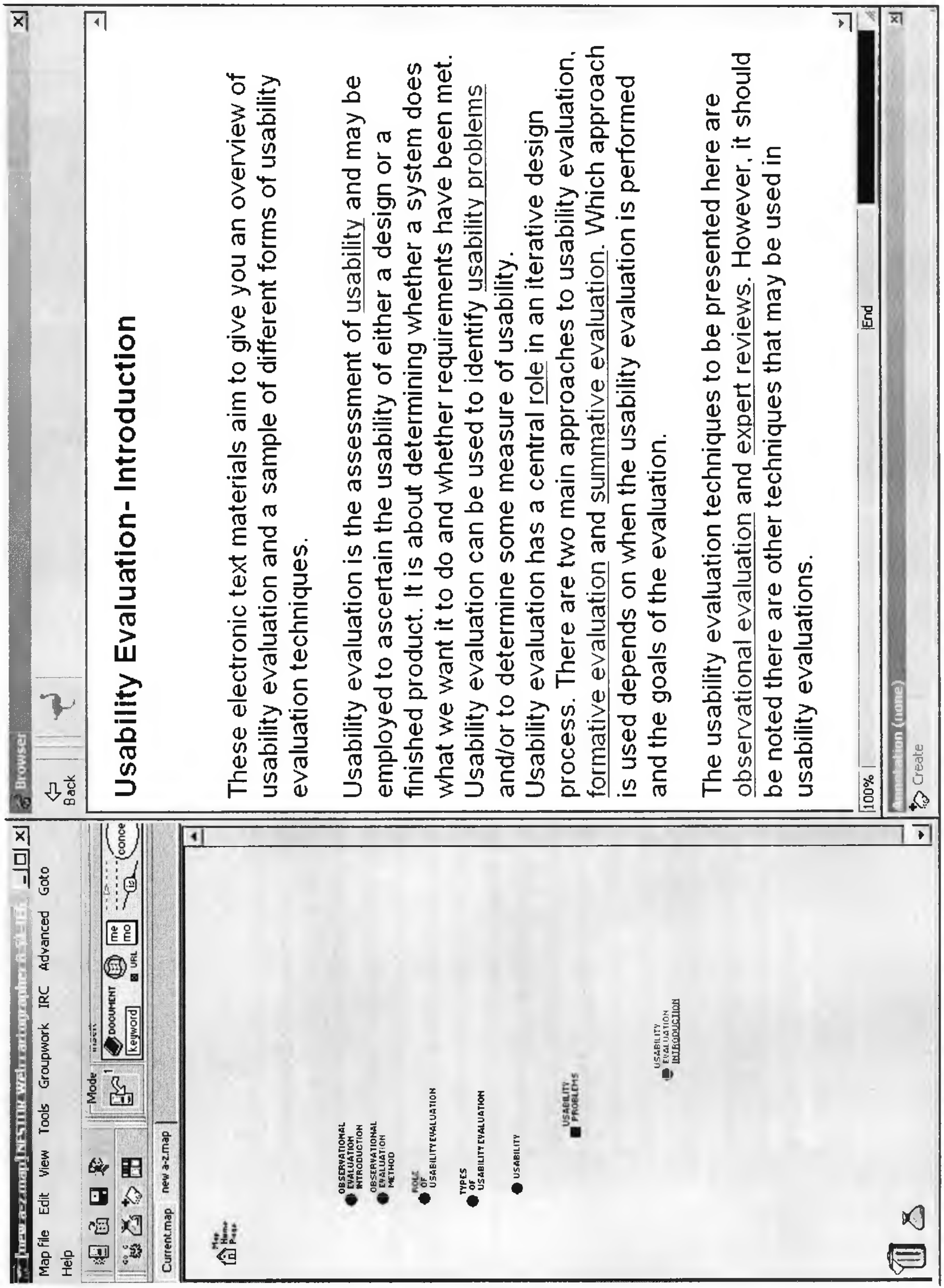

Figure 5.4. The creating A-Z condition.

Learning Measures

As in experiment 1 and part A of this experiment, the pre-test (see appendix 4.3) was administered to participants as a control measure to determine whether they all had the same level of background knowledge of the content of the electronic text. This consisted of seven questions testing their knowledge of usability evaluations.

Three dependent variables were employed to test H_4 – H_6: cognitive engagement (as measured by participants' think-aloud verbalisations whilst using the electronic text), feelings of ownership for learning (as measured by the ownership questionnaire; see appendix 4.7), and knowledge construction (as measured by performance on a transfer task and a concept-mapping task; see appendices 4.8 and 4.9). These were the same measures as in experiment 1 and their details were described in chapter 4. Details of the analyses of this data and the results are described in section 5.3.2.1.

Navigation and Usability Problem Measures

As in experiment 1 and part A in this experiment, navigation behaviour was assessed through post-hoc analyses of the log files collected in the Nestor Navigator browser. Also as in experiment 1, transcriptions of participants' verbalisations were used to identify the usability problems experienced. Details of how these measures were analysed were described in chapter 4, and additional analyses and the results are described in section 5.3.2.2.

5.2.3 Part C – Creating vs Using Contents Lists

5.2.3.1. Participants

Fourteen undergraduates on an introductory HCI course in the autumn term 2003 at City University took part in part C (see table 5.3). These were different people to those who participated in parts A and B. As with participants in experiment 1 and those in parts A and B here, all had attended an introductory HCI lecture, but had not yet attended a lecture on usability evaluation (the topic presented in the electronic text).

Age Range		Gender		Undergraduate/ Postgraduate		Computer Experience		WWW Experience		WWW Use	
18-29yrs.	14	Female	7	Undergrad.	14	< 1 yr.	0	< 1 yr.	0	Daily	12
30-39yrs.	0	Male	7	Postgrad.	0	1-3 yrs.	0	1-3 yrs.	1	Weekly	2
40-49yrs.	0	-	-	-	-	4-5 yrs.	0	4-5 yrs.	5	Monthly	0
50+ yrs.	0	-	-	-	-	5+ yrs.	14	5+ yrs.	8	Rarely	0

Table 5.3. The number of participants in each demographic category, and the number in each category for computer and web experience and web use for part C.

5.2.3.2. Equipment and Materials

Participants in part C used a Jeran Technology PC running an Intel Pentium 4 processor and 512MB RAM with a 19" monitor, keyboard and mouse. They also used the Nestor Navigator browser to access and navigate the same electronic text on usability evaluation. Participants' interactions and verbalisations as they used the electronic text were recorded on a video camera. In addition, log files in Nestor Navigator recorded the navigation aid used, the page visited and the time the page was visited.

5.2.3.3. Design and Procedure

A between-subjects design was employed and participants were randomly assigned to experimental conditions. The independent variable was the type of navigation provided and the three experimental conditions were:

1. using a contents list (+ embedded links)
2. creating a contents list(+ embedded links)
3. using embedded links

As in parts A and B, the fourteen new participants in this experiment were randomly assigned to either the using contents list or creating contents list conditions, seven in each condition. Again as in parts A and B, the third condition (embedded links) comprised of data collected from the seven embedded links participants in experiment 1.

In the first condition (using a contents list), participants could access the electronic text through a contents list of page titles that showed all twenty-three pages in the electronic text displayed in a left-hand window and/or through embedded links within the text and/or by using a back button (see figure 5.5). The contents list displayed the titles of pages in the electronic text in one possible logical order and used indentations to indicate conceptual groupings. In the second condition (creating a contents list), participants initially could only access the text through embedded links within the text and/or by using a back button. Each time the participant visited a new page, the page title was added to the left-hand window (see figure 5.6). This contents list could then be used to navigate the text and participants could re-arrange the page titles on the list according to their own preferences, thus creating their own personalised contents list. In the creating contents list condition, the node for the page that was currently being displayed was shown in red (rather than the standard blue). It should be noted that in the using contents list condition the map gave no indication of which page was currently being displayed (this is a feature of Nestor Navigator).

The experimental procedure was the same as in experiment 1 (see section 4.2.3 in chapter 4 for more details), and parts A and B of this experiment, except that in part 3 of the procedure, participants in the "creating contents list" condition created their contents list. See appendices 4.2 – 4.5 for the experimental script, the pre-test and demographic questionnaire, training instructions, and the instructions for the task as they used the electronic text. See appendices 4.7 – 4.9 for the ownership questionnaire, written transfer task instructions and the concept mapping task instructions.

Learning Measures

As in experiment 1 and parts A and B in this experiment, the pre-test (see appendix 4.3) was administered to participants as a control measure to determine whether they all had the same level of background knowledge of the content of the electronic text. This consisted of seven questions testing their knowledge of usability evaluations.

Three dependent variables were employed to test H_4 – H_6: cognitive engagement (as measured by participants' think-aloud verbalisations whilst using the electronic text), feelings of ownership for learning (as measured by an ownership questionnaire see appendix 4.7), and knowledge construction (as measured by performance on a transfer task and a concept-mapping task see appendices 4.8 and 4.9).

Navigation and Usability Problem Measures

As in experiment 1 and parts A and B in this experiment, navigation behaviour was assessed through post-hoc analyses of the log files collected in the Nestor Navigator browser. Also as in experiment 1, the transcripts of participants' verbalisations were used to identify the usability problems experienced. Details of how these measures were analysed were described in chapter 4, and additional analyses and the results are described in section 5.3.3.3.

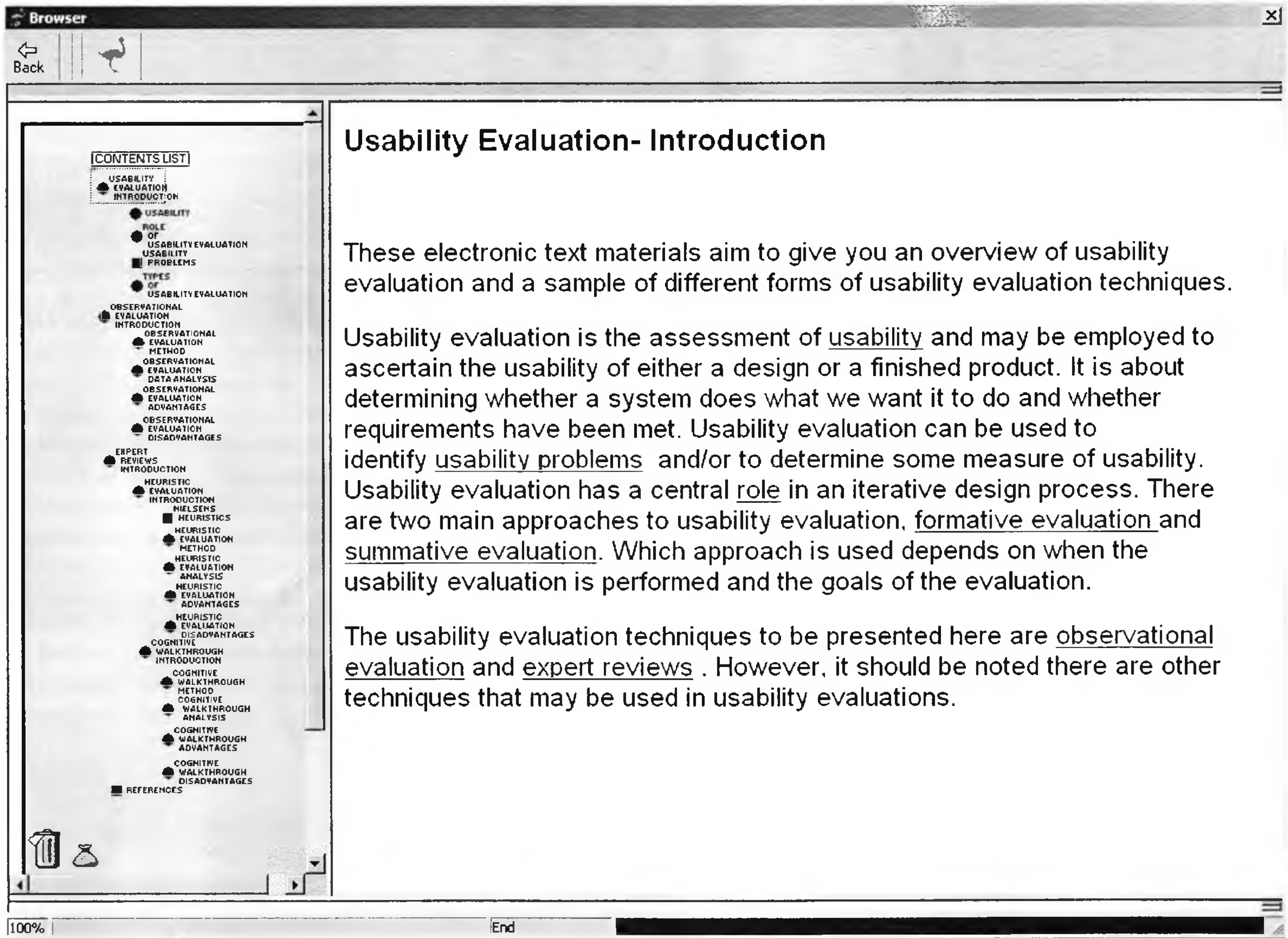

Figure 5.5. The using contents list condition.

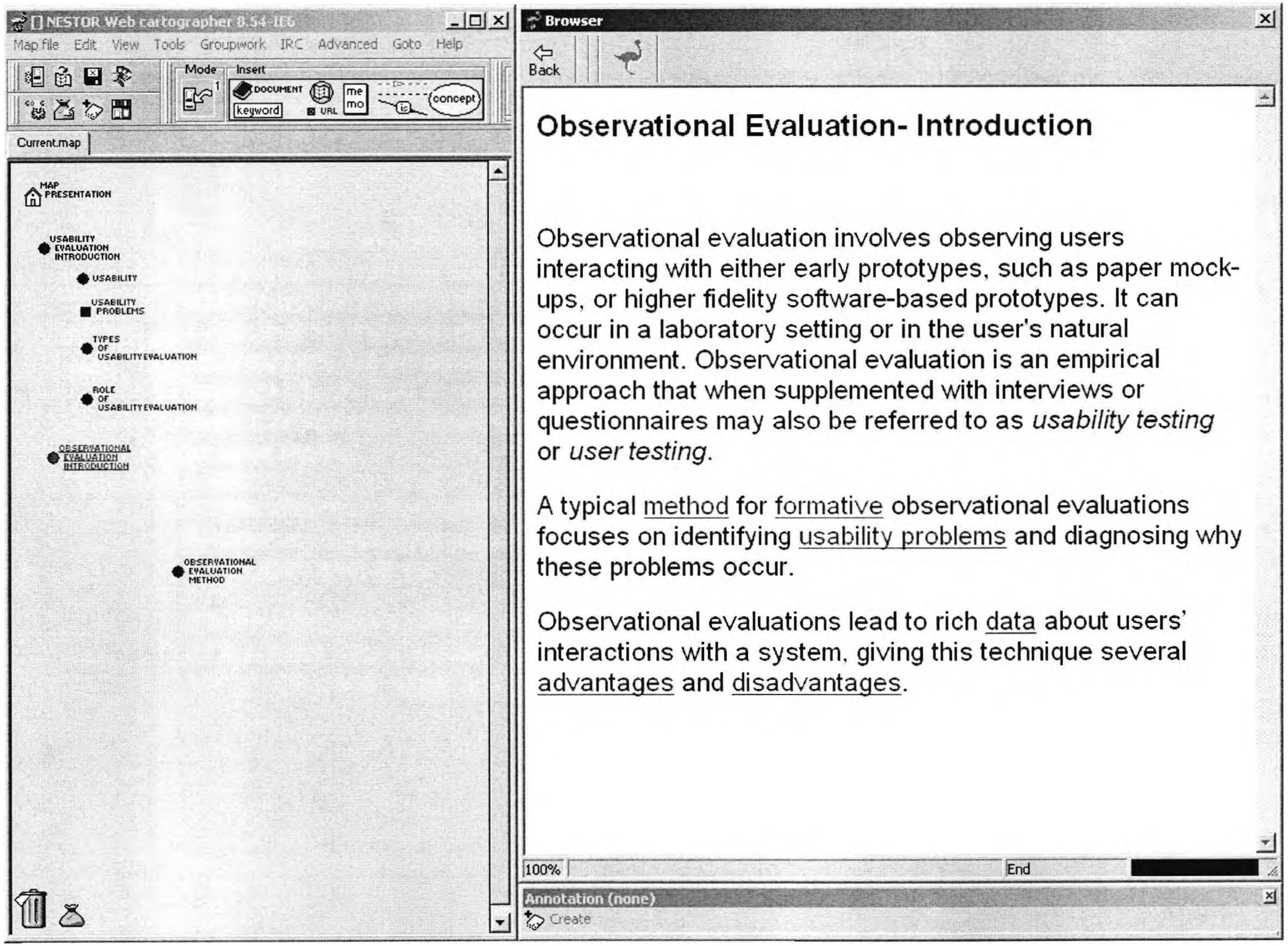

Figure 5.6. The creating contents list condition.

5.3 Analysis and Results

This section presents the analysis and results for the learning measures taken to test H_4-H_6 in parts A-C of this experiment. In addition, the results of post-hoc analyses of the participants' navigation behaviour from log files, and usability problems extracted from participants' think-aloud verbalisations are presented. Where inferential statistics are calculated, statistical significance is set at the 0.05 level. Graphs are only shown when significant differences, borderline significant differences, or differences approaching significance, are found, and include error bars showing +1 standard error.

The reliability and validity of the cognitive engagement, ownership, and knowledge construction measures for parts A and B of this experiment were checked together with the data from experiment 1 and were discussed in chapter 4. Also, the coding schemes for cognitive engagement and usability problems were developed with three think-aloud transcripts taken from the total pool of seventy-one transcripts in experiments 1 and 2. As discussed in chapter 4, this analysis was performed together since the procedures and measures for experiments 1 and 2 were the same. The pre-test, ownership questionnaire and knowledge construction measures for part C of this experiment, were checked separately. This is because this data was analysed at a different time to the rest of the data since part C was conducted at a later date than experiment 1 and parts A and B of experiment 2. The reliability and validity checking for the pre-tests, ownership questionnaires, written transfer tasks and concept maps for part C of this experiment are described in section 5.3.3.

5.3.1 Part A – Creating vs Using Maps

In this section, the results for the learning measures from the using map and creating map conditions in part A of this experiment are presented. Data from the embedded links condition in experiment 1 was also included in these analyses as a baseline comparison condition. As discussed in the method section, the use of this data is valid since the procedures and measures of experiments 1 and 2 are the same.

It should also be noted that the data for one participant in the creating map condition was removed from these analyses. This participant was determined to be an outlier since it was apparent that they had completely misunderstood the experimental instructions when they used the electronic texts on usability evaluation. They thought that they were simply supposed to create a map of the electronic texts and did not think about the electronic texts in terms of choosing a usability evaluation technique for the given scenario. As a result they were unable to make a decision about which usability evaluation technique to choose by the end of the allocated forty-five minutes for the task.

5.3.1.1. Part A: Learning Measures

Pre-test

The pre-test was marked as described in experiment 1 (see appendix 4.10 for the marking scheme). The mean of the overall marks for the seven pre-test questions on usability evaluation was 20.56%. The standard deviation was 12.32. A check for overall marks of three standard deviations above the mean or more revealed that there were no extreme cases.

Cognitive Engagement

As in experiment 1, participants' think-aloud transcripts were coded for instances of cognitive engagement activities (see appendix 4.12 for the coding scheme and appendix 4.13 for an example coded transcript). Some cognitive engagement activities required more complex mental operations, so were given a score of 2 (Connecting Experiences, Connecting to the Task Setting, Critiquing Text Content, Monitoring Understanding, Planning/Strategy), whereas all others were more simple so were given a score of 1 (Alertness, Employing Selected Technique, Monitoring Navigation, Restating Understanding, Selecting Technique). Cognitive engagement scores were then calculated by summing the activity scores for each transcript.

A Kruskal-Wallis ANOVA was used to analyse cognitive engagement scores. Kruskal-Wallis ANOVAs were also performed to examine differences across conditions for the number of instances of each cognitive engagement activity. Where significant differences were revealed, post-hoc pair-wise comparisons were made using the Siegal and Castellan (1988) method. The results of these analyses are summarised in table 5.4. See appendix 5.1 for further details of the outputs for each of these analyses.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Cognitive engagement scores	using map – 99.14; creating map – 34.17; embedded links – 77.43.	Non-significant.	N/A
Planning/ Strategy	using map – 4.57; creating map – 1.17; embedded links – 1.71. **(see figure 5.7)**	**Approaching significance (H(2,20)=5.214, p=0.074)**	using map vs creating map.
Connecting to the Task Setting	using map – 5.71; creating map – 2.33; embedded links – 2.43.	Non-significant.	N/A
Connecting Experiences	using map – 15.71; creating map – 5.00; embedded links – 11.14.	Non-significant.	N/A
Critiquing Text Content	using map – 4.29; creating map – 0.50; embedded links – 2.71.	Non-significant.	N/A
Monitoring Understanding	using map – 5.43; creating map – 0.67; embedded links – 5.14. **(see figure 5.8)**	**Borderline significance (H(2,20)=5.935, p=0.051)**	using map vs creating map; embedded links vs creating map.
Employing Selected Technique	using map – 5.00; creating map – 1.67; embedded links – 3.29.	Non-significant.	N/A
Restating Understanding	using map – 8.29; creating map – 1.83; embedded links – 11.43. **(see figure 5.9)**	**Approaching significance (H(2,20)=5.056, p=0.080)**	No significant post-hoc tests.
Alertness	using map – 6.29; creating map – 1.33; embedded links – 2.71.	Non-significant.	N/A
Selecting Technique	using map – 3.57; creating map – 2.50; embedded links – 7.29.	Non-significant.	N/A
Monitoring Navigation	using map – 4.57; creating map – 7.50; embedded links – 6.43.	Non-significant.	N/A

Table 5.4. Results of analyses for cognitive engagement.

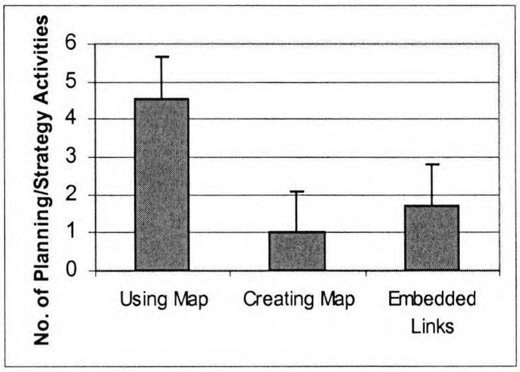

Figure 5.7. Average number of Planning/Strategy activities identified from verbalisations (+ 1 standard error) for each condition in part A.

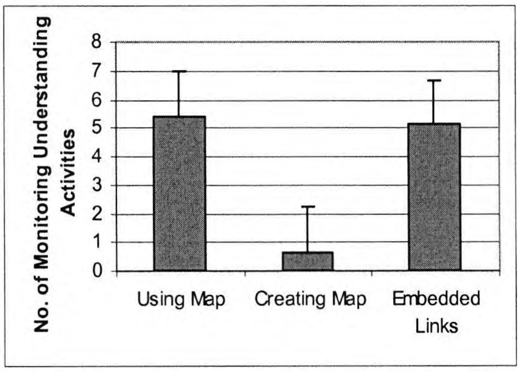

Figure 5.8. Average number of Monitoring Understanding Activities identified from verbalisations (+ 1 standard error) for each condition in part A.

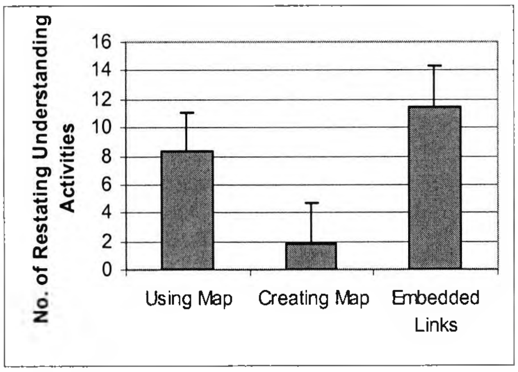

Figure 5.9. The number of Restating Understanding activities identified from verbalisations (+ 1 standard error) for each condition in part A.

Ownership

Total ownership and the average ratings for each factor were calculated as in experiment 1. Kruskal-Wallis ANOVAs were employed to assess differences across conditions and, where appropriate, non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. The results of these analyses are summarised in table 5.5. See appendix 5.2 for further details of the outputs of these analyses.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total ownership scores (out of 5)	using map – 4.56; creating map – 3.56; embedded links – 3.78. **(see figure 5.10).**	**Significant** (H(2,20)=8.226,p=0.016).	using map vs. creating map; using map vs. embedded links.
Control factor (out of 5)	using map – 4.69; creating map – 3.70; embedded links – 3.54. **(see figure 5.10)**	**Significant** (H(2,100)=26.19,p=0.000)	using map vs. creating map; using map vs. embedded links.
Responsibility factor (out of 5)	using map – 4.51; creating map – 3.63; embedded links – 3.97. **(see figure 5.10)**	**Significant** (H(2,100)=16.70,p=0.000)	using map vs. creating map; using map vs. embedded links.
Value factor (out of 5)	using map – 4.43; creating map – 3.22; embedded links – 3.86. **(see figure 5.10)**	**Significant** (H(2,60)=9.64,p=0.008)	using map vs. creating map.

Table 5.5. Results of analyses performed on the ownership questionnaire ratings.

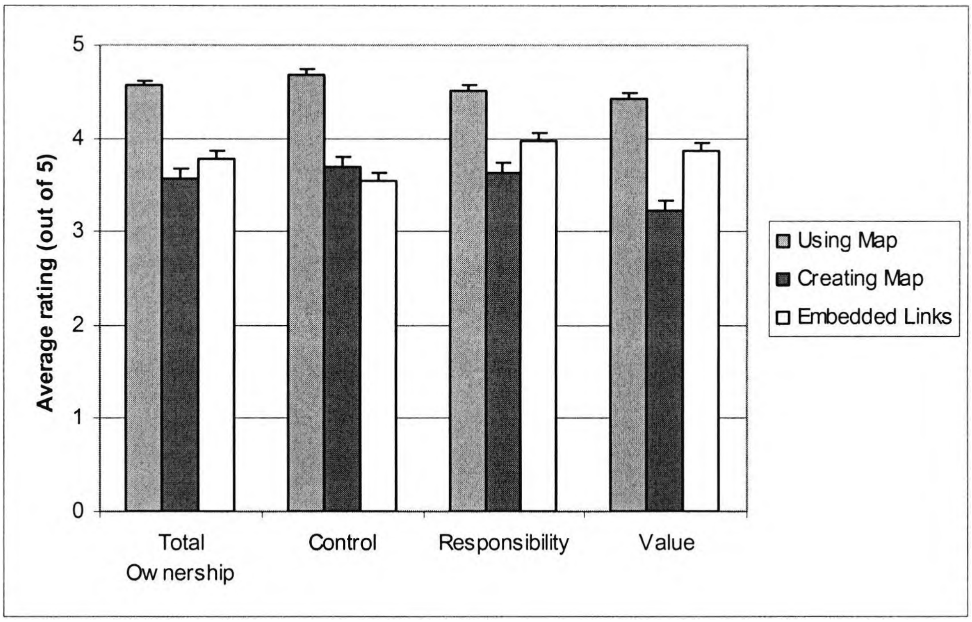

Figure 5.10. Average total ownership and average ratings (+ 1 standard error) on the control, responsibility and value factors for part A.

Knowledge Construction

The written transfer tasks were marked blind to the condition as described in experiment 1 (see appendix 4.16 for the marking scheme). Kruskal-Wallis ANOVAs were employed to assess differences between conditions for all aspects that the transfer tasks were marked on, and, where appropriate, non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. The results of these analyses are summarised in table 5.6. For further details of the outputs of these analyses see appendix 5.3.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total transfer task mark (%)	using map – 48.10; creating map – 35.56; embedded links – 28.57.	Non-significant.	N/A.
A - Description of usability evaluation and its purpose (%)	using map – 51.43; creating map – 46.67; embedded links – 42.86.	Non-significant.	N/A.
B - Details of the evaluation techniques presented in the electronic text (%)	using map – 60.00; creating map – 40.00; embedded links – 45.71.	Non-significant.	N/A.
C - Understanding of how the usability evaluation techniques relate to each other (%)	using map – 62.86; creating map – 20.00; embedded links – 28.57.	Non-significant.	N/A.
D - Explanation of how each technique relates to the given usability evaluation setting (%)	using map – 45.71; creating map – 53.33; embedded links – 34.29.	Non-significant.	N/A.
E - Details of how the chosen technique will be employed (%)	using map – 42.86; creating map – 30.00; embedded links – 8.57. **(see figure 5.11)**	**Significant (H(2,20)=6.531, p=0.038)**	using map vs hypertext.
F - Argument quality (%)	using map – 25.71; creating map – 23.33; embedded links – 11.43.	Non-significant.	N/A.

Table 5.6. Results of analyses for all aspects that the transfer tasks were marked on for part A.

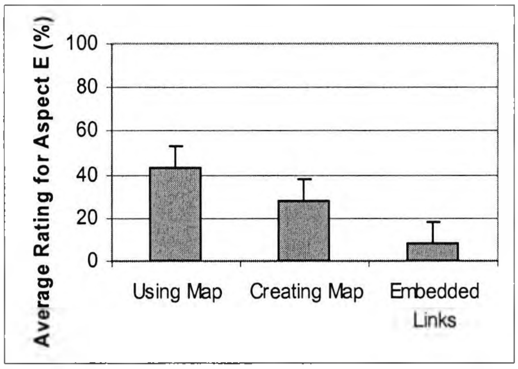

Figure 5.11. Average ratings on aspect E of the transfer task (+ 1 standard error) for part A.

The concept maps were marked blind to the condition as described in experiment 1. The quantitative marks (number of nodes + number of links represented) were analysed using a parametric ANOVA and Tukey post-hoc pair-wise comparison tests. The qualitative marks (the quality of nodes and links; see appendix 4.18 for the marking scheme) were analysed using a Kruskal-Wallis ANOVA and post-hoc pair-wise comparisons using the Siegal and Castellan (1988) method. The results of these analyses are summarised in table 5.7. For further details of the outputs of these analyses see appendix 5.4.

Analysis	Average for each condition	ANOVA	Significant post-hoc tests
Quantitative concept map mark	using map – 50.86; creating map – 32.67; embedded links – 21.43. **(see figure 5.12)**	**Parametric ANOVA significant** ($F(2,20)=13.490$, $p=0.000$)	Tukey: using map vs creating map; using map vs embedded links.
Qualitative concept map mark (%)	using map – 58.93; creating map – 46.67; embedded links – 39.64. **(see figure 5.13)**	**Kruskal-Wallis approaching significance** ($H(2,20)=5.614$, $p=0.060$)	Siegal and Castellan: using map vs embedded links.

Table 5.7. Results of analyses for the qualitative and quantitative concept map marks for part A.

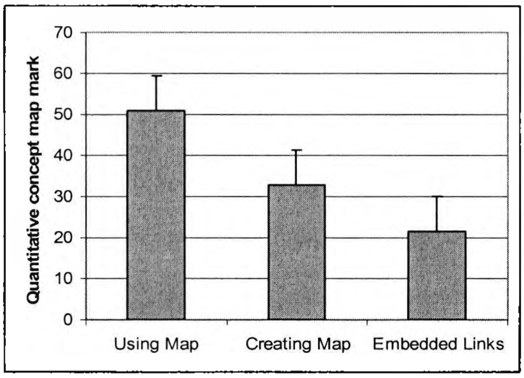

Figure 5.12. Average quantitative concept map marks (+ 1 standard error) for part A.

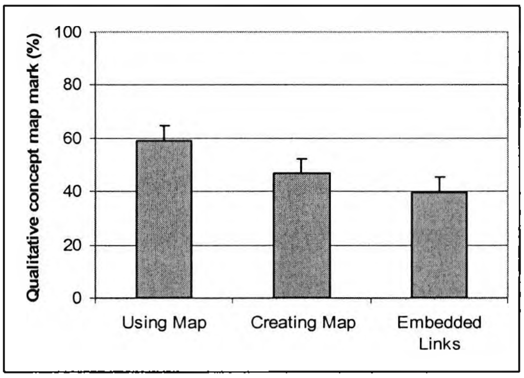

Figure 5.13. Average qualitative concept map marks (+ 1 standard error) for part A.

5.3.1.2. Part A: Navigation and Usability Measures

This section presents the results of post-hoc analyses performed on the navigation and usability measures for part A to further explore participants' behaviour during the experiment, and to look for patterns to provide potential explanations for the findings on the learning measures. The aim is to compare differences between conditions on the navigation behaviour and usability problem measures with differences that arose for the learning measures.

Navigation Behaviour

The participants' navigation behaviour was analysed in three ways in this experiment: the total number of operations (clicks); the number of different pages visited; and back button, map and link usage. The analysis of the number of operations and the number of different pages was the same as in experiment 1. The analysis of back button, map and link usage was new for experiment 2 and was not included in experiment 1. The Nestor log files recorded whether the back button, map or links were used for each operation and the back, map and link usage was calculated as a percentage of the total number of operations. Similar measures of navigation aid use have been used in previous research on navigation in electronic texts (e.g. McDonald and Stevenson, 1998; Catledge and Pitkow (1995), Tauscher and Greenberg, 1997; Danielson, 2002; Zeiliger et al, 1997; Zeiliger et al, 1999).

The number of operations and the number of different pages visited were analysed using parametric ANOVAs. The results of these analyses are summarised in table 5.8. For further details of the outputs of these analyses see appendix 5.5.

Analysis	Average for each condition	ANOVA
No. of operations	using map – 58.71; creating map – 85.67; embedded links – 117.43.	Non-significant.
No. of different pages visited (max 23)	using map – 21.14; creating map – 19.33; embedded links – 20.43.	Non-significant.

Table 5.8. Results of analyses for the number of operations and number of different pages visited for part A.

Between-subjects t-tests were employed to compare usage for the using map and creating map conditions (see table 5.9; see appendix 5.6 for further details of the outputs of these analyses). The embedded links condition was not included in this analysis since navigation in this condition could only be either through embedded links or the back button, and the split between link usage and back usage was 48% to 52% respectively. As such, the percentage usage of links and the back button would necessarily be higher than in the other two conditions.

Usage Analysis	Average for each condition	T-Test
% Back	using map – 16.90; creating map – 38.03. **(see figure 5.14)**	**Significant ($t(11)$=-4.080, p=0.002).**
% Link	using map – 30.90; creating map – 43.40. **(see figure 5.15)**	**Significant ($t(11)$=-2.301, p=0.042).**
% Map	using map – 52.21; creating map – 18.57. **(see figure 5.16)**	**Significant ($t(11)$=4.603, p=0.001).**

Table 5.9. Back, link and map usage analysis for the using map and creating map conditions in part A.

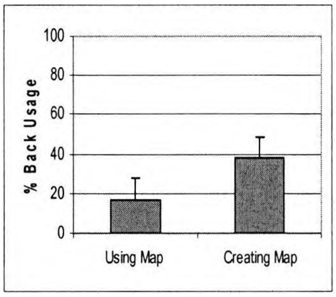

Figure 5.14. Average % back usage (+ 1 standard error) for the using map and creating map conditions.

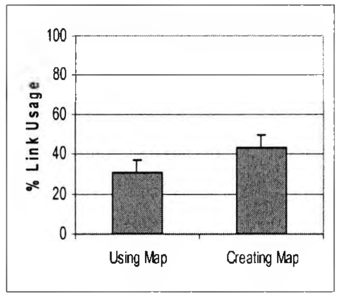

Figure 5.15. Average % link usage (+ 1 standard error) for the using map and creating map conditions.

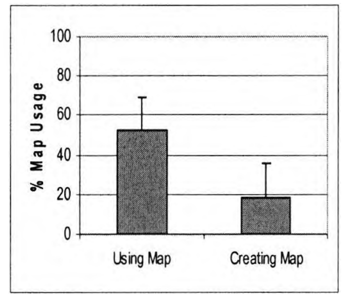

Figure 5.16. Average % map usage (+ 1 standard error) for the using map and creating map conditions.

Usability Problems

Instances of usability problems were identified from the think-aloud transcripts using the criteria described in chapter 4. A total of 225 problem instances were identified from the verbal protocol transcriptions of participants in the using map, creating map and embedded links conditions in part A of experiment 2. As in experiment 1 the number of unique problems and the total severity of problems per participant were also determined. The data was then analysed as in experiment 1.

The number of instances, number of unique problems and total severity per participant were analysed using Kruskal Wallis ANOVAs to assess differences across conditions. The results of these analyses are summarised in table 5.10. For further details of the outputs of these analyses see appendix 5.7.

Analysis	Average per participant for each condition	Kruskal Wallis ANOVA
Problem Instances	using map – 14.86; creating map – 8.17; embedded links – 10.29.	Non-significant.
Unique Problems	using map – 12.29; creating map – 7.33; embedded links – 9.14.	Non-significant.
Total Problem Severity	using map – 24.43; creating map – 16.17; embedded links – 20.43.	Non-significant.

Table 5.10. Results of analyses performed on problem instances, unique problems and total problem severity for part A.

Finally, the usability problems were categorised into the types of problems that occurred in each condition as in experiment 1. In addition to the categories described in experiment 1 in chapter 4, two new categories were added to encompass the new types of usability problems that were experienced by participants in this experiment, over and above those for experiment 1. These are shown in table 5.11.

As in experiment 1, for each category that occurred within each condition, the average number of unique problems per participant in each severity rating was calculated. Table 5.12 and figure 5.17 shows how these categories of problems were distributed across conditions and their severity (for a full list of the problems that fell under each category for each condition in part A see appendix 5.8).

Category Name	Category Description
Creating Aggregate Navigation Aid	Problems specific to navigating, interacting with, and creating navigation aids using Nestor Navigator.
General Interface	Problems associated with general interface mechanisms on the Nestor browser such as the scroll bar and link colour changes.

Table 5.11. New categories of usability problems for experiment 2.

		Using Map	Creating Map	Embedded Links
General Confusion	Cosmetic	-	-	-
	Minor	-	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**0.29**
Hardware	Cosmetic	-	-	-
	Minor	-	0.17	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**0.17**	**-**
Text Content	Cosmetic	0.29	-	-
	Minor	1.57	1.00	0.57
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**1.86**	**1.00**	**0.57**
Text Presentation	Cosmetic	0.43	-	-
	Minor	1.00	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**1.43**	**-**	**-**
Using Aggregate Navigation Aid	Cosmetic	0.14	-	-
	Minor	1.57	-	-
	Major	0.57	-	-
	Catastrophe	-	-	-
	Total	**2.29**	**-**	**-**
Creating Aggregate Navigation Aid	Cosmetic	-	-	-
	Minor	-	2.67	-
	Major	-	1.00	-
	Catastrophe	-	-	-
	Total	**-**	**3.67**	**-**
Navigation Predicting	Cosmetic	-	-	-
	Minor	0.57	0.33	0.57
	Major	-	0.33	0.14
	Catastrophe	-	-	-
	Total	**0.57**	**0.67**	**0.71**
Navigation	Cosmetic	-	-	-

Disorientation	Minor	-	-	0.86
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**0.86**
Navigation Text Structure	Cosmetic	-	-	-
	Minor	0.29	0.17	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.29**	**0.17**	**-**
Navigation Efficiency	Cosmetic	-	-	-
	Minor	3.14	0.67	2.14
	Major	0.14	-	0.43
	Catastrophe	-	-	-
	Total	**3.29**	**0.67**	**2.57**
Understanding Text	Cosmetic	0.29	-	0.57
	Minor	1.86	0.67	2.43
	Major	0.29	0.17	0.86
	Catastrophe	-	-	-
	Total	**2.43**	**0.83**	**3.86**
General Interface	Cosmetic	-	-	-
	Minor	0.14	0.17	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.14**	**0.17**	**-**
Other	Cosmetic	-	-	-
	Minor	-	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**0.29**

Table 5.12. Average number of unique problems per participant in each category for each condition in part A and their severity.

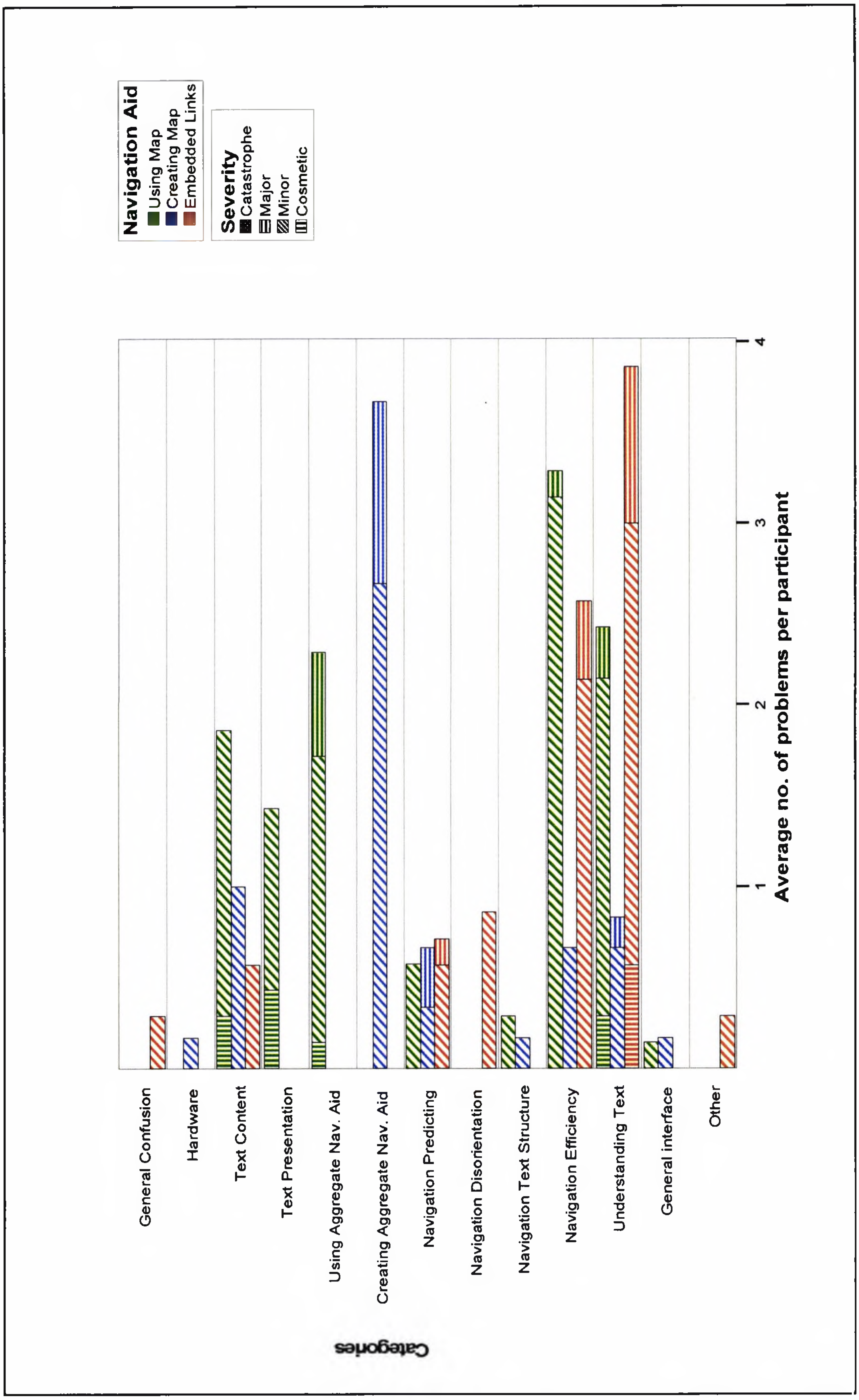

Figure 5.17. Graph showing average number of unique problems per participant in each category for each condition in part A and their severity.

Figure 5.17 reveals that participants in the using map condition on average experienced more problems in the "Navigation Efficiency" category than any other category, and nearly all of these were minor problems. Also the number of problems in this category was higher than for the creating map and embedded links conditions. They were also the only condition to experience problems in the "Text Presentation" category and all of these problems were either minor or cosmetic. Problems in the "Using Aggregate Navigation Aid" category included major, minor and cosmetic problems, the majority being minor problems. Participants in the using map condition experienced more problems in the "Text Content" category than participants in other conditions, and all of these were either minor or cosmetic problems. However, it is notable that they did not experience problems in the "General Confusion", "Navigation Disorientation", "Hardware" and "Other" categories.

Participants in the creating map condition on average experienced more problems in the "Creating Aggregate Navigation Aid" category compared to any other category. Over one quarter of these problems were major problems, and the rest minor problems. More problems were experienced in this category than in any other category across all experimental conditions. In addition, problems in the "Hardware" category were unique to this condition, although there were very few of these problems and they were minor problems only. Participants in the creating map condition experienced the lowest number of problems in the "Understanding Text" and "Navigation Efficiency" categories compared to the other conditions in part A. However, they did not experience any problems in the "General Confusion" "Text Presentation", "Navigation Disorientation" and "Other" categories.

Finally, although the actual problems experienced in the embedded links condition are the same as those reported in experiment 1, they are described here in comparison with the problems experienced in the using and creating map conditions in part A. In this condition problems mainly fell into the "Understanding Text" category and the majority of these were minor problems. Problems in the "Navigation Disorientation", "General Confusion" and "Other" categories were unique to the embedded links condition and did not occur with any of the other types of navigation aids. Problems in these categories were generally minor. However, it may also be noted that participants in the embedded links condition did not experience any problems in the "Navigation Text Structure", "Text Presentation", "General Interface" and "Hardware" categories.

5.3.2 Part B – Creating vs Using A-Z Indices

This section presents the analysis and results for the learning measures and the navigation and usability problem measures for the using A-Z and creating A-Z conditions in part B of this experiment. As in part A, data from the embedded links condition in experiment 1 was also included in these analyses as a baseline comparison condition.

5.3.2.1. Part B: Learning Measures

Pre-test

The pre-tests for part B were marked as in experiment 1 and part A of this experiment. The mean of the overall marks for the pre-test was 20.32%. The standard deviation was 13.23. A participant in the using A-Z condition received an overall mark of 66%. This was determined to be an extreme case, since the overall mark was more than three standard deviations above the mean, and as such the data for this participant was removed from subsequent analyses.

Cognitive Engagement

Cognitive engagement scores were calculated as in experiment 1 and part A of this experiment. They were then analysed for differences across conditions using a Kruskal-Wallis ANOVA. Kruskal-Wallis ANOVAs were also performed to examine differences across conditions for each cognitive engagement activity. The results of these analyses are summarised in table 5.. For further details of the outputs of these analyses see appendix 5.9.

Analysis	Average for each condition	Kruskal-Wallis ANOVA
Cognitive engagement scores	using A-Z – 56.00; creating A-Z – 38.57; embedded links – 77.43.	Non-significant.
Planning/ Strategy	using A-Z – 3.00; creating A-Z – 1.00; embedded links – 1.71.	Non-significant.
Connecting to the Task Setting	using A-Z – 2.50; creating A-Z – 1.86; embedded links – 2.43.	Non-significant.
Connecting Experiences	using A-Z – 7.33; creating A-Z – 5.71; embedded links – 11.14.	Non-significant.
Critiquing Text Content	using A-Z – 1.17; creating A-Z – 0.29; embedded links – 2.71.	Non-significant.
Monitoring Understanding	using A-Z – 4.83; creating A-Z – 1.86; embedded links – 5.14.	Non-significant.
Employing Selected Technique	using A-Z – 2.67; creating A-Z – 2.57; embedded links – 3.29.	Non-significant.
Restating Understanding	using A-Z – 2.50; creating A-Z – 4.00; embedded links – 11.43.	Non-significant.

Alertness	using A-Z – 2.33; creating A-Z – 1.43; embedded links – 2.71.	Non-significant.
Selecting Technique	using A-Z – 5.50; creating A-Z – 5.29; embedded links – 7.29.	Non-significant.
Monitoring Navigation	using A-Z – 5.33; creating A-Z – 3.86; embedded links – 6.43.	Non-significant.

Table 5.13. Results of analyses for cognitive engagement in part B.

Ownership

Total ownership and average ratings on each factor were calculated as in experiment 1. Kruskal-Wallis ANOVAs were employed to assess differences across conditions for responses to the ownership questionnaire. The results of these analyses are summarised in table 5.14. For further details of the outputs of these analyses see appendix 5.10.

Analysis	Average for each condition	Kruskal-Wallis ANOVA
Total ownership scores (out of 5)	using A-Z – 4.00; creating A-Z – 3.80; embedded links – 3.78.	Non-significant.
Control factor (out of 5)	using A-Z – 3.57; creating A-Z – 3.82; embedded links – 3.54.	Non-significant.
Responsibility factor (out of 5)	using A-Z – 4.20; creating A-Z – 3.94; embedded links – 3.97.	Non-significant.
Value factor (out of 5)	using A-Z – 4.39; creating A-Z – 3.90; embedded links – 3.86.	Non-significant.

Table 5.14. Results of analyses of the ownership questionnaire ratings for part B.

Knowledge Construction

The written transfer tasks were marked blind to the condition as described in experiment 1 and part A of this experiment. Kruskal-Wallis ANOVAs were employed to assess differences between conditions for all aspects that the transfer tasks were marked on for part B. The results of these analyses are summarised in table 5.15. For further details of the outputs of these analyses see appendix 5.11.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total transfer task mark (%)	using A-Z – 54.44; creating A-Z – 32.38; embedded links – 28.57.	Non-significant.	N/A.
A - Description of usability evaluation and its purpose (%)	using A-Z – 56.67; creating A-Z – 42.86; embedded links – 42.86.	Non-significant.	N/A.

B - Details of the evaluation techniques presented in the electronic text (%)	using A-Z – 60.00; creating A-Z – 31.43; embedded links – 45.71.	Non-significant.	N/A.
C - Understanding of how the usability evaluation techniques relate to each other (%)	using A-Z – 53.33; creating A-Z – 17.14; embedded links – 28.57.	Non-significant.	N/A.
D - Explanation of how each technique relates to the given usability evaluation setting (%)	using A-Z – 63.33; creating A-Z – 34.29; embedded links – 34.29.	Non-significant.	N/A.
E - Details of how the chosen technique will be employed (%)	using A-Z – 53.33; creating A-Z – 42.86; embedded links – 8.57. **(see figure 5.18)**	**Approaching significance** (H(2,20)=5.168,p=0.075)	using A-Z vs. embedded links.
F - Argument quality (%)	using A-Z – 40.00; creating A-Z – 25.71; embedded links – 11.43.	Non-significant.	N/A.

Table 5.15. Results of analyses for all aspects that the transfer tasks were marked on for part B.

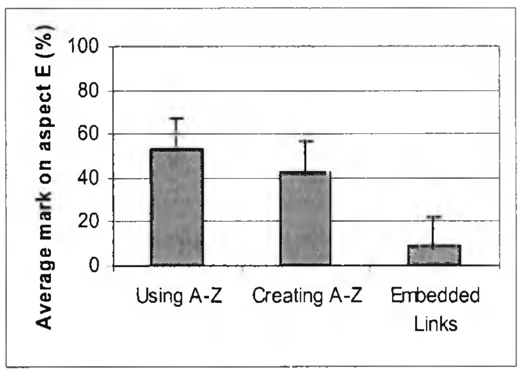

Figure 5.18. Average rating on aspect E of the transfer task (+1 standard error) for part B.

The concept maps were marked blind to the condition as described in experiment 1 and part A of this experiment. The quantitative marks (number of nodes + number of links represented) were analysed using a parametric ANOVA. The qualitative marks (quality of nodes and links represented) were analysed using a Kruskal-Wallis ANOVA. The results of these analyses are summarised in table 5.16. For further details of the outputs of these analyses see appendix 5.12.

Analysis	Average for each condition	ANOVA
Quantitative concept map mark	using A-Z – 36.00; creating A-Z – 20.14; embedded links – 21.43.	Parametric ANOVA non-significant
Qualitative concept map mark (%)	using A-Z – 57.08; creating A-Z – 36.07; embedded links – 39.64.	Kruskal-Wallis non-significant

Table 5.16. Results of analyses for the qualitative and quantitative concept map marks for part B.

5.3.2.2. Part B: Navigation and Usability Measures

This section presents the results of post-hoc analyses of navigation behaviour and usability problems performed for part B to further explore participants' behaviour during the experiment, and to look for patterns to provide potential explanations for the findings on cognitive engagement, ownership and knowledge construction.

Navigation Behaviour

As in part A, the participants' navigation behaviour was analysed in three ways: the total number of operations (clicks); the number of different pages visited; and back, A-Z and link usage.

The number of operations and the number of different pages visited were analysed using parametric ANOVAs. The results of these analyses are summarised in table 5.17. For further details of the outputs of these analyses see appendix 5.13.

Analysis	Average for each condition	ANOVA
No. of operations	using A-Z – 71.67; creating A-Z – 76.14; embedded links – 117.43.	Non-significant.
No. of different pages visited (max 23)	using A-Z – 21.83; creating A-Z – 19.29; embedded links – 20.43.	Non-significant.

Table 5.17. Results of analyses for the number of operations and number of different pages visited for part B.

As in part A, the back, A-Z and link usage was calculated as a percentage of the total number of operations for each condition in part B. Between-subjects t-tests were then employed to compare usage for the using A-Z and creating A-Z conditions (see table 5.18; for further details of the outputs of these analyses see appendix 5.14). Again, as in part A the embedded links condition was not included in this comparison.

Usage Analysis	Average for each condition	T-Test
% Back	using A-Z – 22.30; creating A-Z – 36.21. **(see figure 5.19).**	**Approaching significance** **($t(11)$=-1.997, p=0.071).**
% Link	using A-Z – 36.00; creating A-Z – 43.54.	Non-significant.
% A-Z	using A-Z – 41.71; creating A-Z – 20.25.	Non-significant.

Table 5.18. Back, link and A-Z usage comparisons for the using A-Z and creating A-Z conditions in part B.

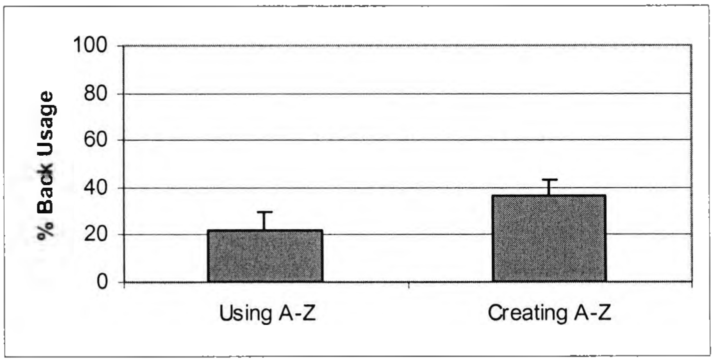

Figure 5.19. Average % back usage (+ 1 standard error) for the using A-Z and creating A-Z conditions.

Usability Problems

As in experiment 1 and part A of this experiment, instances of usability problems were identified from the think-aloud transcripts using the criteria described in chapter 4. A total of 219 problem instances were identified from the verbal protocol transcriptions of participants in the using map, creating map and embedded links conditions in part A of experiment 2. As in experiment 1 and part A of this experiment, the number of unique problems and the total severity of problems per participant were also determined. The data was then analysed as in experiment 1.

The number of instances, number of unique problems and total severity per participant were analysed using Kruskal-Wallis ANOVAs to assess differences across conditions for part B. The results of these analyses are summarised in table 5.19 (see appendix 5.15 for details of the output of these analyses).

Analysis	Average per participant for each condition	Kruskal Wallis ANOVA
Problem Instances	using A-Z – 12.50; creating A-Z – 10.29; embedded links – 10.29.	Non-significant.
Unique Problems	using A-Z – 10.83; creating A-Z – 8.43; embedded links – 9.14.	Non-significant.
Total Problem Severity	using A-Z – 24.17; creating A-Z – 20.71; embedded links – 20.43.	Non-significant.

Table 5.19. Results of analyses performed on problem instances, unique problems and total problem severity for part B.

Finally, as in experiment 1 and part A of this experiment, the usability problems were categorised into the types of problems that occurred in each condition. The new categories added in part A were also included here. As in experiment 1, for each category that occurred within each condition, the average number of unique problems per participant in each severity rating was determined. Table 5.20 and figure 5.20 shows how these categories of were distributed across conditions and their severity (for a full list of problems that fell into each category for each condition in part B see appendix 5.16).

		Using A-Z	Creating A-Z	Embedded Links
General Confusion	Cosmetic	-	-	-
	Minor	0.17	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.17**	**-**	**0.29**
Hardware	Cosmetic	-	-	-
	Minor	-	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**-**
Text Content	Cosmetic	-	-	-
	Minor	0.50	0.29	0.57
	Major	0.33	0.29	-
	Catastrophe	-	-	-
	Total	**0.83**	**0.57**	**0.57**
Text Presentation	Cosmetic	0.17	-	-
	Minor	-	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.17**	**-**	**-**
Using Aggregate Navigation Aid	Cosmetic	-	-	-
	Minor	1.67	-	-
	Major	0.50	-	-
	Catastrophe	-	-	-
	Total	**2.17**	**-**	**-**
Creating Aggregate Navigation Aid	Cosmetic	-	-	-
	Minor	-	1.71	-
	Major	-	0.86	-
	Catastrophe	-	0.14	-
	Total	**-**	**2.71**	**-**
Navigation Predicting	Cosmetic	-	-	-
	Minor	1.83	0.57	0.57
	Major	-	-	0.14
	Catastrophe	-	-	-
	Total	**1.83**	**0.57**	**0.71**
Navigation Disorientation	Cosmetic	-	-	-
	Minor	0.83	0.14	0.86
	Major	-	0.29	-
	Catastrophe	-	-	-
	Total	**0.83**	**0.43**	**0.86**
Navigation Text Structure	Cosmetic	-	-	-
	Minor	0.17	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.17**	**-**	**-**

Navigation Efficiency	Cosmetic	-	-	-
	Minor	1.50	0.57	2.14
	Major	1.17	0.57	0.43
	Catastrophe	-	-	-
	Total	**2.67**	**1.14**	**2.57**
Understanding Text	Cosmetic	0.17	0.29	0.57
	Minor	1.00	1.43	2.43
	Major	0.83	0.57	0.86
	Catastrophe	-	0.71	-
	Total	**2.00**	**3.00**	**3.86**
General Interface	Cosmetic	-	-	-
	Minor	-	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**-**
Other	Cosmetic	-	-	-
	Minor	-	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**0.29**

Table 5.20. Average number of unique problems per participant in each category for each condition in part B and their severity.

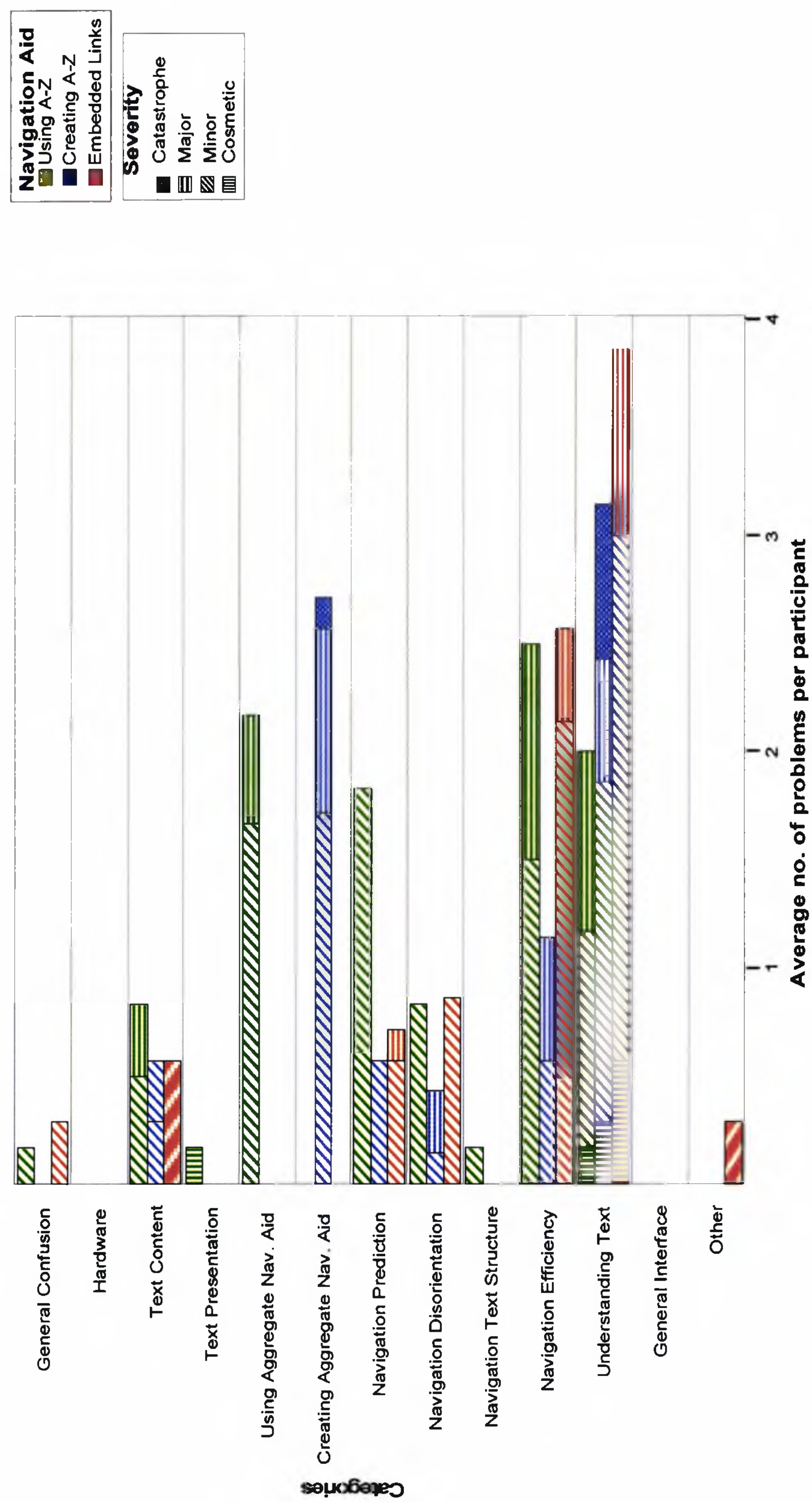

Figure 5.20. Graph showing average number of unique problems per participant in each category for each condition in part B

Figure 5.20 revealed that participants in the using A-Z condition experienced more problems in the "Navigation Efficiency" category than in any other category.

They also experienced the more problems in this category than participants in the other two conditions. Just under half of these were major and the remainder minor. Participants who used an A-Z also experienced more problems in the "Navigation Predicting" and "Text Content" categories compared to participants in the other conditions. Problems in the "Navigation Text Structure" and "Text Presentation" categories were unique to the using A-Z condition. Approximately one quarter of the problems in the "Using Aggregate Navigation Aid" category were major problems, and the rest were minor. It is also notable that participants in the using A-Z condition did not experience problems in the "Hardware", "Other" and "General Interface" categories.

Participants in the creating A-Z condition experienced more problems in the "Understanding Text" category than any other category and approximately one quarter of these were classified as catastrophic problems. A small proportion of the problems in the "Creating Aggregate Navigation Aid" category were classified as catastrophic, and approximately one third were major and the remainder were minor problems. Participants in the creating A-Z condition did not experience problems in the "General Confusion", "Hardware", "Text Presentation", "Navigation Text Structure", "General Interface" and "Other" categories.

Finally, although the actual problems experienced in the embedded links condition are the same as those reported in experiment 1, and part A of this experiment, they are described here in comparison with the problems experienced in the using and creating A-Z conditions in part B. Problems experienced by participants in the embedded links condition fell mainly into the "Understanding Text" category, and the majority of these were minor problems. Participants in the embedded links condition also experienced the greatest number of problems in this category compared to any other condition in part B. Problems in the "Other" category were unique to the embedded links condition and did not occur with any of the other types of navigation aids. Problems in these categories were generally minor. Participants in the embedded links condition did not experience any problems in the "Navigation Text Structure", "General Interface", "Hardware" and "Text Presentation" categories.

5.3.3 Part C – Creating vs Using Contents Lists

This section presents the analysis and results for the learning measures and navigation and usability problem measures from the using contents list and creating contents list conditions in part C of experiment 2. As in parts A and B, data from the embedded links condition in experiment 1 was also included in these analyses as a baseline comparison condition.

As discussed earlier, the analysis of the data from the fourteen new participants' pre-tests, ownership questionnaires and knowledge construction measures for part C was conducted at a different time to the analysis of parts A and B. Accordingly, the reliability and validity of the data for part C was checked separately, and the results of this checking is reported in this section.

It should also be noted that one participant in the creating contents list condition was determined to be an outlier. During the experiment they experienced problems that were not experienced by any other participants where some pages of the electronic text could not be opened immediately. As such data from this participant was removed from subsequent analyses.

5.3.3.1. Part C: Reliability and Validity Checking for the Pre-test, Ownership and Knowledge Construction Measures

Pre-test

The pre-test on usability evaluation was marked blind to the condition by the author in the same way as in experiment 1, and parts A and B of this experiment. To check the reliability and validity of the marking, an expert in usability evaluation external to this research independently marked a random sample of seven pre-tests taken from those completed by the fourteen participants in part C of this experiment. A Spearman's rank correlation was employed to check how well the marks corresponded (see appendix 5.17 for details of the outputs of this analysis). This revealed a significant correlation between the two marks (rho(7)=0.929, p=0.003). This indicates that the marking was reliable and valid.

Ownership

The thirteen-statement ownership questionnaire used in the analysis of experiment 1 and parts A and B of this experiment was also employed here in part C. An internal reliability analysis was conducted with the questionnaire responses from the participants in part C (see appendix 5.18 for the details of the output of this analysis). This revealed a Cronbach's alpha of 0.77 indicating good internal reliability.

Knowledge Construction

The written transfer tasks were marked blind to the condition by the author in the same way as described in experiment 1 and parts A and B of this experiment. To check the reliability of the marking, an expert in usability evaluation external to this research marked a random sample of seven written transfer tasks from those completed by the fourteen participants in part C of this experiment. A Spearman's rank correlation was employed to check how well the two sets of marks corresponded (see appendix 5.19 for details of the outputs of this analysis). This revealed a significant correlation between the two sets of marks (rho(7)=0.764, p=0.046). This suggests that the marking was reliable and that the marking scheme had good validity.

As in experiment 1, the concept maps were given a quantitative mark assessing the *detail* of the concept maps and a qualitative mark assessing the *quality* of the concept maps. To check the reliability of the qualitative marks, a random sample of seven concept maps were taken from those produced by the fourteen participants in part C, and were second marked by an expert on usability evaluation who was external to this project. A Spearman's rank statistic was calculated (see appendix 5.20 for details of the outputs of this analysis). This revealed significant correlations for the appropriateness of the link structure (rho(7)=0.765, p=0.045). However, the correlation for the relevance of links did not reach significance (rho(7)=0.633, p=0.127). Nevertheless, since the sample used in the correlation was only seven, the correlation for the link marks was significant, and the correlation coefficient for the node relevance was over 0.6, overall the reliability and validity of the marking was considered acceptable.

5.3.3.2. Part C: Learning Measures Results

Pre-test

The mean of the overall marks for the pre-test was 18.27%. The standard deviation was 12.80. A check for overall marks of three standard deviations above the mean or more revealed that there were no extreme cases.

Cognitive Engagement

Cognitive engagement scores were calculated as in experiment 1. They were then analysed for differences across conditions using a Kruskal-Wallis ANOVA, and Siegal and Castellan (1988) post-hoc comparison tests. Kruskal-Wallis ANOVAs and Siegal and Castellan (1988) post hoc tests were also performed to examine differences across conditions for each cognitive engagement activity. The results of these analyses are summarised in table 5.21. For further details of the outputs of these analyses see appendix 5.21.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Cognitive engagement scores	using contents list – 45.43; creating contents list – 35.67; embedded links – 77.43.	Non-significant.	N/A.
Planning/ Strategy	using contents list – 1.71; creating contents list – 1.33; embedded links – 1.71.	Non-significant.	N/A.
Connecting to the Task Setting	using contents list – 3.29; creating contents list – 1.33; embedded links – 2.43.	Non-significant.	N/A.
Connecting Experiences	using contents list – 7.43; creating contents list – 5.50; embedded links – 11.14.	Non-significant.	N/A.
Critiquing Text Content	using contents list – 0.43; creating contents list – 1.17; embedded links – 2.71.	Non-significant.	N/A.
Monitoring Understanding	using contents list – 2.00; creating contents list – 0.50; embedded links – 5.14. **(see figure 5.21)**	**Significant ($H(2,20)=7.059$, $p=0.029$).**	embedded links vs creating contents.
Employing Selected Technique	using contents list – 2.29; creating contents list – 1.83; embedded links – 3.29.	Non-significant.	N/A.
Restating Understanding	using contents list – 4.57; creating contents list – 3.67; embedded links – 11.43.	Non-significant.	N/A.
Alertness	using contents list – 0.86; creating contents list – 0.33; embedded links – 2.71.	Non-significant.	N/A.
Selecting Technique	using contents list – 5.71; creating contents list – 4.50; embedded links – 7.29.	Non-significant.	N/A.
Monitoring Navigation	using contents list – 2.29; creating contents list – 5.67; embedded links – 6.43.	Non-significant.	N/A.

Table 5.21. Results of analyses for cognitive engagement in part C.

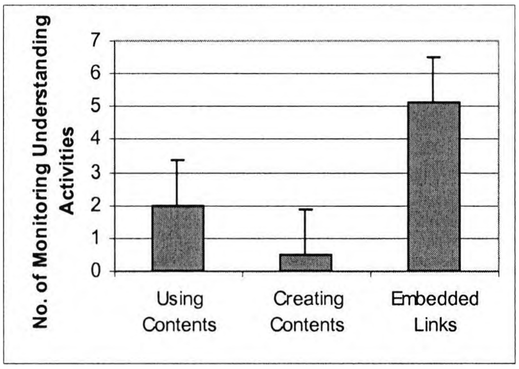

Figure 5.21. Average number of Monitoring Understanding activities identified from verbal protocols (+ 1 standard error)in part C.

Ownership

Total ownership and the average ratings for each factor were calculated as in experiment 1. Kruskal-Wallis ANOVAs were employed to assess differences across conditions, and where appropriate non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. The results of these analyses are summarised in table 5.22. See appendix 5.22 for further details of the outputs of these analyses.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total ownership scores (out of 5)	using contents list – 4.04; creating contents list – 4.03; embedded links – 3.78.	Non-significant.	N/A.
Control factor (out of 5)	using contents list – 4.11; creating contents list – 4.00; embedded links – 3.54. **(see figure 5.22)**	**Significant** (H(2,100)=7.279,p=0.026)	using contents vs. embedded links.
Responsibility factor (out of 5)	using contents list – 3.86; creating contents list – 4.00; embedded links – 3.97.	Non-significant.	N/A.
Value factor (out of 5)	using contents list – 4.24; creating contents list – 4.11; embedded links – 3.86.	Non-significant.	N/A.

Table 5.22. Results of analyses performed on the ownership questionnaire ratings for part C.

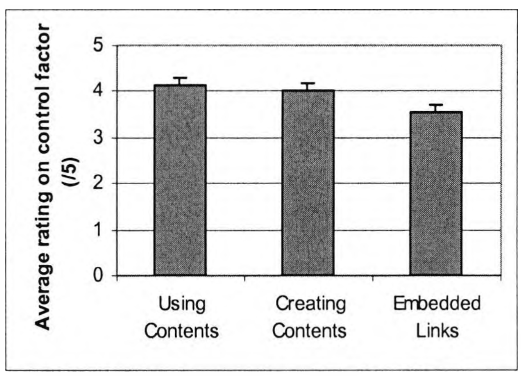

Figure 5.22. Average ratings on the control factor (+ 1 standard error)for part C.

Knowledge Construction

The written transfer tasks were marked blind to the experimental condition as described in experiment 1. Kruskal-Wallis ANOVAs were employed to assess differences across conditions for all aspects that the transfer tasks were marked on, and where appropriate non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. The results of these analyses are summarised in table 5.23. For further details of the outputs of these analyses see appendix 5.23.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total transfer task mark (%)	using contents list – 51.43; creating contents list – 41.33; embedded links – 28.57. **(see figure 5.23)**	**Significant (H(2,19=6.090, p=0.048).**	using contents vs embedded links.
A - Description of usability evaluation and its purpose (%)	using contents list – 42.86; creating contents list – 40.00; embedded links – 42.86.	Non-significant.	N/A.

B - Details of the evaluation techniques presented in the electronic text (%)	using contents list – 68.57; creating contents list – 60.00; embedded links – 45.71. **(see figure 5.23)**	**Approaching significance (H(2,19=5.613, p=0.060)**	using contents vs embedded links.
C - Understanding of how the usability evaluation techniques relate to each other (%)	using contents list – 51.43; creating contents list – 24.00; embedded links – 28.57.	Non-significant.	N/A.
D - Explanation of how each technique relates to the given usability evaluation setting (%)	using contents list – 48.57; creating contents list – 48.00; embedded links – 34.29.	Non-significant.	N/A.
E - Details of how the chosen technique will be employed (%)	using contents list – 37.14; creating contents list – 32.00; embedded links – 8.57. **(see figure 5.23)**	**Significant (H(2,19)=6.416, p=0.040)**	using contents vs embedded links.
F - Argument quality (%)	using contents list – 60.00; creating contents list – 44.00; embedded links – 11.43. **(see figure 5.23)**	**Significant (H(2,19)=11.742, p=0.003)**	using contents vs embedded links.

Table 5.23. Results of analyses for all aspects that the transfer tasks were marked on for part A.

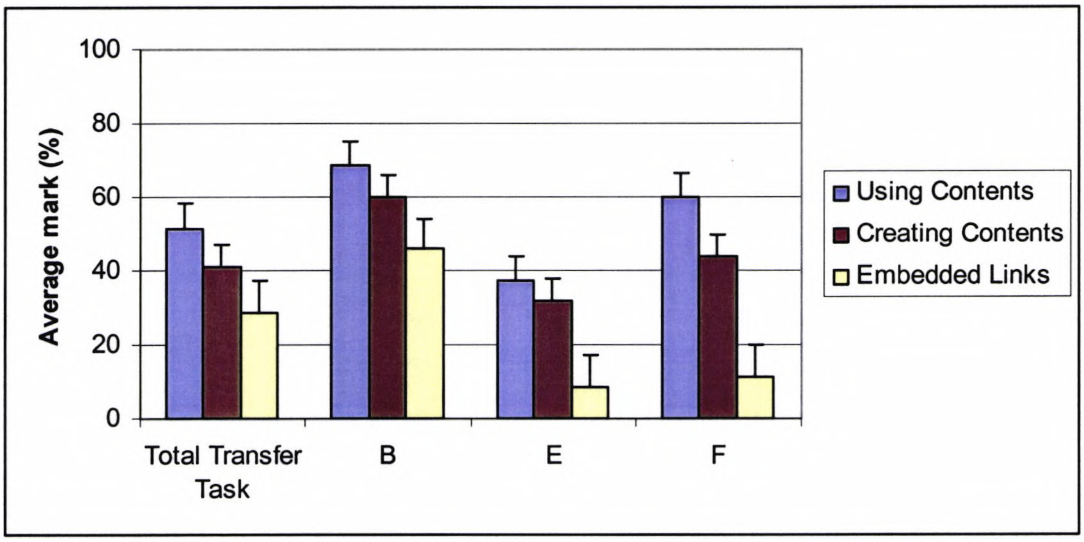

Figure 5.23. Average marks on aspects B, E and F on the written transfer task (+ 1 standard error) for part C.

The concept maps were marked blind to the experimental condition as described in experiment 1 and in parts A and B of this experiment. The quantitative marks (the number of nodes and links represented) were analysed using a parametric ANOVA and Tukey post-hoc pair-wise comparison tests. The qualitative marks (quality of nodes and links) were analysed using a Kruskal-Wallis ANOVA and post-hoc pair-wise comparisons using the Siegal and Castellan (1988) method. The results of these analyses are summarised in table 5.24. For further details of the outputs of these analyses see appendix 5.24.

Analysis	Average for each condition	ANOVA	Significant post-hoc tests
Quantitative concept map mark	using contents list – 33.86; creating contents list – 33.50; embedded links – 21.43. **(see figure 5.24)**	**Parametric ANOVA significant** ($F(2,20)=5.187$, $p=0.017$)	Tukey: using contents list vs embedded links; creating contents list vs embedded links.
Qualitative concept map mark (%)	using contents list – 56.78; creating contents list – 43.33; embedded links – 39.64. **(see figure 5.25)**	**Kruskal-Wallis significant** ($H(2,20)=7.671$, $p=0.022$)	Siegal and Castellan: using contents list vs embedded links.

Table 5.24. Results of analyses for the qualitative and quantitative concept map marks for part C.

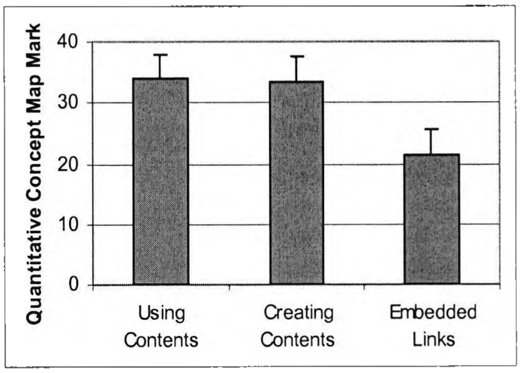

Figure 5.24. Average quantitative concept map marks (+ 1 standard error) for part C.

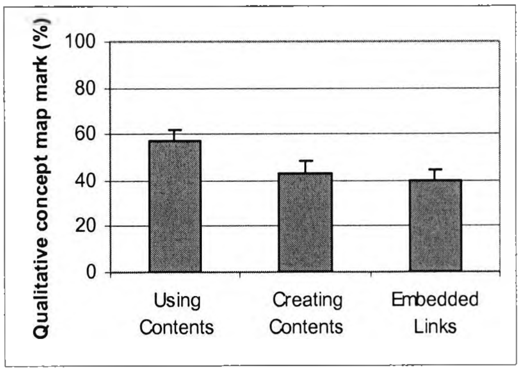

Figure 5.25. Average qualitative concept map marks (+ 1 standard error) for part C.

5.3.3.3. Part C: Navigation and Usability Measures

This section presents the results of post-hoc analyses of the navigation and usability measures performed for part C to further explore participants' behaviour during the experiment, and to look for patterns to provide potential explanations for the findings on the learning measures.

Navigation Behaviour

The participants' navigation behaviour was analysed in three ways in this experiment: the total number of operations (clicks); the number of different pages visited; and back, contents list and link usage.

For the number of operations and the number of different pages visited, Levene tests for homogeneity of variance indicated that the variances were different across conditions, so that a parametric ANOVA could not be used. Instead Kruskal-Wallis ANOVAs and Siegal and Castellan (1988) post-hoc tests were used. The results of these analyses are summarised in table 5.25. For further details of the outputs of these analyses see appendix 5.25.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
No. of operations	using contents list – 63.43; creating contents list – 144.33; embedded links – 117.43. **(see figure 5.26)**	**Approaching significance (H(2,20)=5.176, p=0.075)**	creating contents vs. using contents.
No. of different pages visited (max 23)	using contents list – 21.71; creating contents list – 22.67; embedded links – 20.43.	Non-significant.	N/A.

Table 5.25. Results of analyses for the number of operations and number of different pages visited for part C.

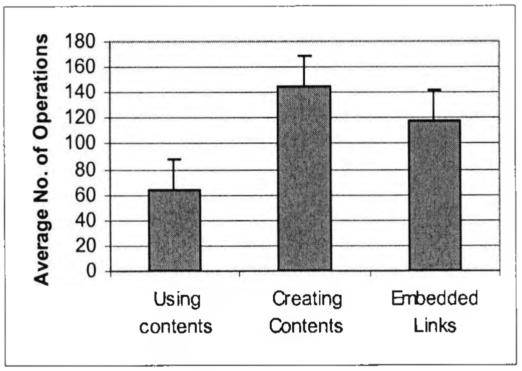

Figure 5.26. The average number of operations (+ 1 standard error) performed in each condition for part C.

As in parts A and B, the back, contents list and link usage was calculated as a percentage of the total number of operations for each condition in part C. Between-subjects t-tests were then employed to compare usage for the using contents list and creating contents list conditions (see table 5.26; for further details of the outputs of these analyses see appendix 5.26.). Again, the embedded links condition was not included in this comparison.

Usage Analysis	Average for each condition	T-Test
% Back	using contents list – 24.71; creating contents list – 29.93.	Non-significant.
% Link	using contents list – 58.11; creating contents list – 39.05. **(see figure 5.27)**	**Significant (t(11)=3.696, p=0.004).**
% Contents List	using contents list – 17.17; creating contents list – 31.02. **(see figure 5.28)**	**Significant (t(11)=-2.468, p=0.031).**

Table 5.26. Back, link and contents list usage comparisons for the using contents list and creating contents list conditions in part C.

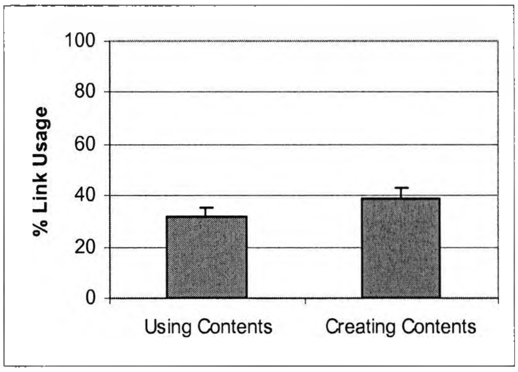

Figure 5.27. Average % link usage (+ 1 standard error) for the using and creating contents list conditions.

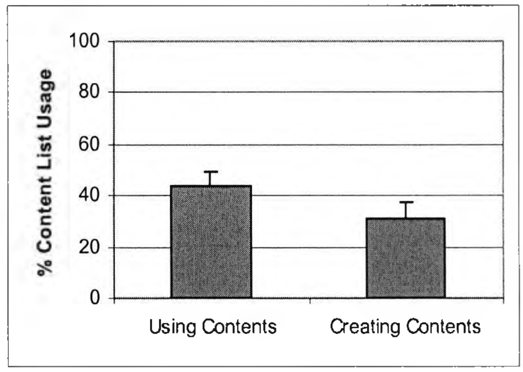

Figure 5.28. Average % contents list usage (+ 1 standard error) for the using and creating contents list conditions.

Usability Problems

As in experiment 1, and parts A and B of this experiment, instances of usability problems were identified from the think-aloud transcripts using the criteria described in chapter 4. A total of 219 problem instances were identified from the verbal protocol transcriptions of participants in the using map, creating map and embedded links conditions in part A of experiment 2. As in experiment 1, and parts A and B of this experiment, the number of unique problems and the total severity of problems per participant were also determined. The data was then analysed as in experiment 1.

The number of instances, number of unique problems and total severity per participant were analysed using Kruskal-Wallis ANOVAs to assess differences across conditions. The results of these analyses are summarised in table 5.27. For further details of the outputs of these analyses see appendix 5.27.

Analysis	Average per participant for each condition	Kruskal Wallis ANOVA
Problem Instances	using contents list – 7.14; creating contents list – 10.67; embedded links – 10.29.	Non-significant.
Unique Problems	using contents list – 6.71; creating contents list – 9.83; embedded links – 9.14.	Non-significant.
Total Problem Severity	using contents list – 13.29; creating contents list – 21.17; embedded links – 20.43.	Non-significant.

Table 5.27. Results of analyses performed on problem instances, unique problems and total problem severity for part C.

Finally, as in experiment 1, and parts A and B of this experiment, the usability problems were categorised into the types of problems that occurred in each condition.

Also as in experiment 1, for each category that occurred within each condition, the average number of unique problems per participant in each severity rating was calculated. Table 5.28 and figure 5.29 show the average number of problems per participant in each condition that fell into each category and their severity (for a full list of problems that fell into each category for each condition in part C see appendix 5.28).

		Using Contents	Creating Contents	Embedded Links
General Confusion	Cosmetic	-	-	-
	Minor	0.14	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.14**	**-**	**0.29**
Hardware	Cosmetic	-	-	-
	Minor	-	0.17	-
	Major	-	-	-
	Catastropy	-	-	-
	Total	**-**	**0.17**	**-**
Text Content	Cosmetic	-	-	-
	Minor	0.43	0.33	0.57
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.43**	**0.33**	**0.57**
Text Presentation	Cosmetic	-	-	-
	Minor	0.29	0.33	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.29**	**0.33**	**-**
Using Aggregate Navigation Aid	Cosmetic	-	-	-
	Minor	0.71	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**0.71**	**-**	**-**
Creating Aggregate Navigation Aid	Cosmetic	-	-	-
	Minor	-	2.33	-
	Major	-	0.67	-
	Catastrophe	-	-	-
	Total	**-**	**3.00**	**-**
Navigation Predicting	Cosmetic	-	0.33	-
	Minor	0.29	0.17	0.57
	Major	-	-	0.14
	Catastrophe	-	-	-
	Total	**0.29**	**0.50**	**0.71**
Navigation Disorientation	Cosmetic	-	-	-
	Minor	0.43	0.17	0.86
	Major	0.14	-	-

	Catastrophe	-	-	-
	Total	**0.57**	**0.17**	**0.86**
Navigation Text Structure	Cosmetic	-	-	-
	Minor	-	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**-**
Navigation Efficiency	Cosmetic	-	-	-
	Minor	2.29	2.83	2.14
	Major	0.14	0.17	0.43
	Catastrophe	-	-	-
	Total	**2.43**	**3.00**	**2.57**
Understanding Text	Cosmetic	-	-	0.57
	Minor	1.71	1.33	2.43
	Major	0.14	1.00	0.86
	Catastrophe	-	-	-
	Total	**1.86**	**2.33**	**3.86**
General Interface	Cosmetic	-	-	-
	Minor	-	-	-
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**-**
Other	Cosmetic	-	-	-
	Minor	-	-	0.29
	Major	-	-	-
	Catastrophe	-	-	-
	Total	**-**	**-**	**0.29**

Table 5.28. Average number of unique problems per participant in each category for each condition in part C and their severity.

Figure 5.29 shows that participants in the using contents list condition experienced more problems in the "Navigation Efficiency" category than they did in any other category, and the majority of these were minor. They also experienced the lowest number of problems in the "Understanding Text" category compared to any other condition, where again the majority of their problems were minor. For the problems that fell into the "Using Aggregate Navigation Aid" category, that were specific to using a contents list, on average participants experienced less than one problem in this category and these were all minor problems. Participants in the using contents list condition also experienced no problems in the "Hardware", "Navigation Text Structure", "General Interface" and "Other" categories.

Participants in the creating contents condition experienced more problems in the "Navigation Efficiency" and "Creating Aggregate Navigation Aid" categories than in the other categories. They also experienced more problems in the "Navigation Efficiency" category than any other condition, and the majority of these problems were minor problems. In addition, approximately three quarters of the problems in the

"Creating Aggregate Navigation Aid" category were minor and one quarter were major problems. Participants in the creating contents condition experienced no problems in the "General Confusion", "Navigation Text Structure", "General Interface" or "Other" categories.

Finally, although the actual problems experienced in the embedded links condition are the same as those reported in experiment 1, and parts A and B of this experiment, they are described here in comparison with the problems experienced in the using and creating contents conditions in part C. Participants in the embedded links condition experienced the most problems in the "Understanding Text" category compared to the other categories, and experienced more problems in this category than in the other two conditions. The majority of these problems were minor, although some cosmetic and major problems were also experienced. Participants in this condition also experienced the greatest number of problems in the "Navigation Disorientation" and "Navigation Predicting" categories. The problems in the "Navigation Disorientation" category were all minor problems. Of the problems in the "Navigation Predicting" category, the majority of problems were minor, and approximately one fifth were major. Participants in the embedded links condition experienced no problems in the "Hardware", "Navigation Text Structure", "General Interface" and "Text Presentation" categories.

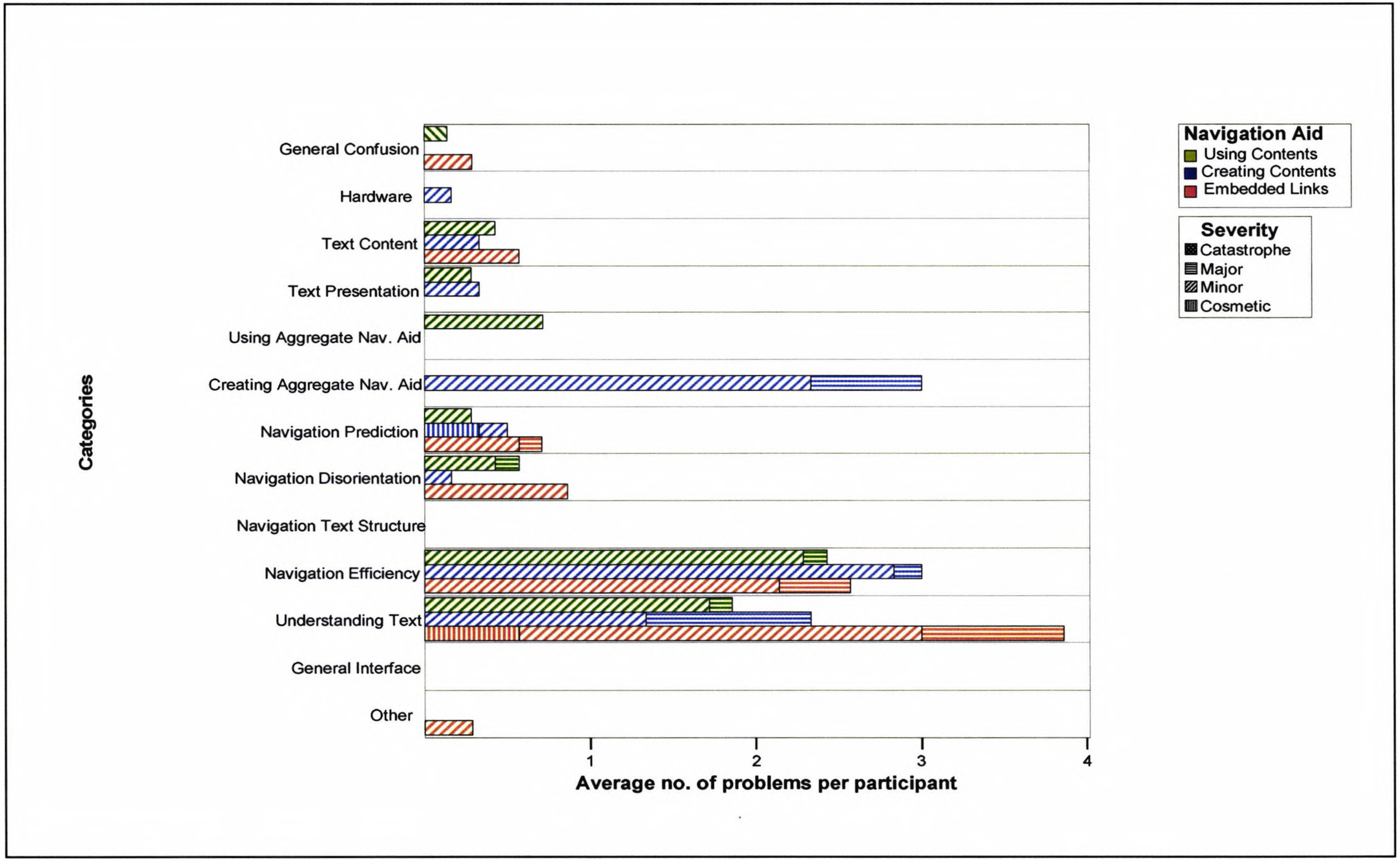

Figure 5.29. Graph showing average number of problems per participant in each category for each condition in part C and their severity.

5.4 Discussion

Based on the framework of constructivism in chapter 3, it was hypothesised that learners who created their own navigation aids would show higher levels of cognitive engagement, would feel higher levels of ownership and would develop higher quality knowledge constructions than those who used existing navigation aids. Overall, the results of parts A, B and C of this experiment indicate that creating navigation aids does influence some aspects of learning, but this was not as predicted. The findings from parts A, B and C are discussed in turn, and implications from each part of this experiment are identified. Finally, findings from all three parts of the experiment are discussed together and conclusions are drawn.

5.4.1 Part A – Creating vs Using Maps

5.4.1.1. Results Summary and Explanation for Findings

This section discusses findings from part A according to each of the learning measures taken to test the hypotheses. Potential explanations for any differences between conditions will be considered in terms of the post-hoc analyses of navigation behaviour and usability problems, as well as in terms of cognitive load theory. The explanations are not intended to be mutually exclusive. The relation of these findings to previous research is also discussed, and implications of the findings from part A are presented.

Cognitive Engagement

Overall the findings on cognitive engagement as measured here were not as predicted in H_4. The main findings were:

- ⇨ No significant differences were found across conditions in part A for the cognitive engagement scores.
- ⇨ Notable differences were found for Planning/Strategy activities and Monitoring Understanding activities, where participants in the using map and embedded links conditions showed evidence of engaging in more of these activities than those in the creating map condition.
- ⇨ Notable differences across conditions were found for Restating Understanding activities, but although the post-hoc tests showed no significant differences between conditions, participants in the using map and embedded links

conditions engaged in more of these activities than participants the creating map condition.

This indicates that in terms of these measures of cognitive engagement, using a map or embedded links is more beneficial than creating a map.

In order to provide some explanation for these results, firstly the findings for the navigation behaviour measures were examined. There were no significant differences across conditions in part A for the number of operations and number of different pages visited. Analysis of the percentage of back and link usage for the using and creating map conditions revealed that participants in the creating map condition showed a significantly higher percentage of back and link usage than those in the using map condition, and accordingly participants in the using map condition showed a significantly higher percentage of map usage than those in the creating map condition. This result is unsurprising. For participants in the creating map condition the embedded links and back button were the participants' only means of navigation until their map was built up. Nevertheless, it does suggest that the using map condition, which was found to lead to a higher number of Planning/Strategy, Restating Understanding and Monitoring Understanding activities, was also associated with higher map use and lower back and link use. Conversely, the creating map condition was found to lead to a lower number of Planning/Strategy, Restating Understanding and Monitoring Understanding activities, and was also associated with higher back and link use and lower map use. This finding is interesting when considered in relation to cognitive load theory.

Higher link and back usage have been related to higher extraneous cognitive load (Niederhauser et al., 2000; Conklin, 1987). When creating a map, extraneous cognitive load may have arisen when participants determined where they wanted to go next in the electronic texts, using either the embedded links or the map they had created. It is anticipated that additional learner control offered by creating a map also would have implications for cognitive load. Participants had to make decisions about the best ways to arrange their map and articulate their ideas, which could also have increased extraneous cognitive load. As such, participants may have had less cognitive resources available to engage in Planning/Strategy, Restating Understanding and Monitoring Understanding activities.

As discussed in chapter 2, some measures of cognitive load include evaluation of dual task performance (Paas & Van Merrienboer, 1993). In this experiment, the act of verbalising and reading/using the electronic text can be considered as a dual task. Performance on the dual task, as assessed through cognitive engagement measures in this case, should be lower if cognitive load is high. Since the number of Planning/Strategy, Restating Understanding and Monitoring Understanding activities were lower in the creating map condition, compared to the using map condition, this may imply that cognitive load was higher in the creating map condition. On the other hand, the provision of a map may reduce cognitive load by assisting with the task of orientation and gives a conceptual overview of the electronic text (McDonald and Stevenson, 1999; Boechler, 2001; Brunstein et al., 2004). When creating a map, initially participants had to rely on the embedded links for navigation and no overview was provided, so they were responsible for constructing a conceptual understanding of the text on their own, thereby incurring higher cognitive load.

However, the back, link and map usage only provides explanation for the differences between the using map and creating map conditions. It does not explain the finding for the embedded links condition since no comparisons were made for back and link usage in the embedded links condition. Since embedded links and the back button were the only forms of navigation available, their use would necessarily be higher than in any other condition. Accordingly, the finding that the embedded links condition had benefits for these aspects of cognitive engagement compared to the creating map condition was considered in light of proposed benefits of embedded links for engagement discussed in previous literature.

As pointed out in Dillon and Gabbard (1998), several reasons have been put forward advocating the use of cross-referential embedded links in electronic text. The following arguments are particularly relevant here: embedded links allow users to explore information in depth and on demand (Collier, 1987); they are attention capturing and engaging to use (Jonnasen, 1989); and they are a natural form of representation, similar to the workings of the human mind (Delany and Gilbert, 1991). In fact, Niederhauser et al. (2000) even suggest that learners benefit from engaging in deeper processing when they use embedded links to compare and contrast content. However, it is interesting that the benefits of embedded links compared to creating maps were not found for the ownership or knowledge construction measures in part A. These results are discussed later in this section.

In order to examine another explanation for the finding that the using map and embedded links conditions led to a higher number of Planning/Strategy, Restating Understanding and Monitoring Understanding activities than the creating map condition, the usability problems experienced by participants were considered. No significant differences between conditions were found for the number of instances and unique usability problems, and the total severity of usability problems. Nevertheless, problems that were specifically related to navigating and interacting in the creating map condition were higher than the number of usability problems in other categories, for all conditions. These problems may provide some explanation for the lower number of Planning/Strategy, Restating Understanding and Monitoring Understanding activities in this condition compared to using a map and using embedded links. These problems may have affected the mental resources the participants had available to engage in Planning/Strategy and Monitoring Understanding activities. These problems may also have increased extraneous cognitive load and diverted participants' mental resources away from engaging in Planning/Strategy, Restating Understanding and Monitoring Understanding activities.

Participants in the creating map condition also experienced markedly fewer problems in the "Understanding Text" and "Navigation Efficiency" categories compared to the using map and embedded links conditions. Although this appears to be a positive finding for the creating map condition, since it reveals a different pattern to the other findings it highlights the fact that explanations for the cognitive engagement findings are not straightforward in terms of the types of usability problems.

Ownership

In relation to H_5, the findings on ownership from part A of this experiment were not as hypothesised. The main findings were:

- ⇨ Participants in the using map condition gave significantly higher total ratings on the ownership questionnaire and the component factors of control and responsibility than participants in the creating map condition and participants in the embedded links condition.
- ⇨ The participants in the using map condition also reported higher feelings of value on the questionnaire than participants in the creating map condition.

Overall, this suggests that using a map is more beneficial in terms of feelings of ownership for learning than creating a map or using embedded links.

In particular, the finding that using a map led to higher feelings of control than creating a map was somewhat surprising. One might expect that allowing a learner to create their own map offers them more control over their learning with the electronic texts, since they are able to create the map according to their own preferences. This contrary finding has implications for our understanding of learner control, highlighting the fact that the control perceived by learners may be different from the apparent level of control offered by the navigation in the interface.

Explanations for the findings on ownership will firstly be considered in terms of the navigation behaviour measures and the usability problem measures. As discussed previously, the percentage map usage was significantly higher, and the back button and link usage significantly lower, in the using map condition than in the creating map condition. Since the using map condition was also associated with significantly higher ownership ratings, this suggests an association between higher map usage and higher feelings of ownership. It also suggests that there may be a negative association between link and back button usage and feelings of ownership.

The number of instances, unique problems and total severity of usability problems showed no significant differences across conditions. In terms of the types of usability problems experienced by participants in part A of this experiment, as with the cognitive engagement scores, it appears that the high number of problems that were specific to navigating and interacting in the creating map condition may account for the lower feelings of ownership in this condition.

Participants in the embedded links condition experienced the greatest number of problems related to understanding the electronic text, as compared to the other two conditions. It was also particularly evident that they were also the only condition to experience problems concerned with disorientation and general confusion. These problems may also provide some explanation for the lower feelings of ownership reported in this condition compared to the using map condition, and may be associated with a higher extraneous cognitive load on participants. It can be hypothesised that usability problems influence how positively or negatively learners feel about using educational electronic texts, and this may have been reflected in participants' responses to the ownership questionnaire in this experiment.

Knowledge Construction

The findings on the knowledge construction measures were not as predicted in H_6. The main findings were:

- ⇨ In the transfer task, participants who used maps were significantly better at giving details of a selected usability evaluation technique (aspect E) than those who used embedded links.

⇨ Participants who used maps produced significantly more detailed hand-drawn concept maps (higher number of nodes and links represented), than those who created their own maps and those who used embedded links.

⇨ Participants who used maps produced significantly higher quality hand-drawn concept maps than those who used embedded links.

Therefore, for aspect E of the transfer task, only using a map provided a significant benefit over embedded links. Creating a map provided no significant benefits over embedded links for this aspect of the transfer task. These findings also suggest that for the level of detail in the hand-drawn concept maps, using a map to navigate is more beneficial than creating a map or using embedded links. Another suggestion from these findings is that in terms of the ability to produce quality hand-drawn concept maps only using a map offers benefits over embedded links alone. Allowing the learner to create their own maps offers no significant benefits over embedded links in terms of the quality of concept maps produced.

Overall, once again, it appears that in terms of these aspects of knowledge construction, using a map is beneficial, whereas allowing learners to create their own maps or using embedded links alone is not.

First of all, the navigation measures were considered in terms of potential explanations for these findings. However, as discussed previously there were no significant differences between conditions for the number of different pages visited, and therefore no explanation could be ascertained from these measures. In addition, for the knowledge construction measures, the majority of significant differences occurred between the using map and embedded links conditions. As such, comparing the back button, link and map usage for the using map and creating map conditions provided no explanation for the differences between the using map and embedded links conditions. However, the fact that back button usage was high in the creating map condition may explain why this condition had no benefits over the using map condition. As discussed in relation to cognitive engagement, excessive back button usage has been associated with higher cognitive load (Neiderhauser et al. 2000).

In the using map condition, the percentage back button usage was lower and map usage higher than in the creating map condition. Again, as discussed earlier in relation to cognitive engagement, the overview provided by the map may have reduced cognitive load by aiding orientation, and thereby reducing the need to use the back button frequently. The map also may have reduced the need for participants to allocate cognitive resources to the development of a mental overview of the electronic text. In addition, the map made the conceptual structure of the electronic text explicit, which may have provided benefits for knowledge construction.

Examination of the types of usability problems revealed similar explanations for differences in the quality of knowledge construction between conditions to those given for the cognitive engagement and ownership measures. In particular, the problems associated with navigating and interacting in the creating map condition, and problems of disorientation and general confusion in the embedded links condition, may have played a role in explaining the lower knowledge construction in these conditions. These problems may also have brought about an increase in extraneous cognitive load, and may have lowered the amount of cognitive resources available for knowledge construction.

Finally, it is noted that it could appear that the better performance on the concept-mapping task of those in the using map condition is due to the fact that participants in that condition were given an "ideal" map of the electronic text which they used to navigate. In the concept-mapping task they may have simply reproduced this map. However, this explanation is refuted since high marks on the concept mapping task required more than simple reproduction of the map. Although exposure to the map in the using map condition may have influenced the marks on this task, a simple reproduction of the map by participants would not have been the sole cause of the significant differences found. The appropriateness of the concept-mapping task as a measure in this experiment is discussed further in chapter 7.

Relation to Previous Research

The finding that using a map is particularly beneficial to aspects of knowledge construction has some similarities, and differences, with previous research into the use of maps as navigation aids discussed in chapter 2. McDonald & Stevenson (1999) found that localised conceptual maps that showed the conceptual structure of an electronic text, provided benefits over electronic text with embedded links in terms of performance on factual knowledge tests of the text content given to participants immediately after using the electronic text and a week later. Conceptual maps also provided benefits over embedded links for performance on deeper knowledge test questions given a week later. The findings that the map was beneficial are in line with those from part A of the present experiment. However, McDonald and Stevenson (1999) also found that conceptual maps had no benefits over embedded links on the deeper questions at immediate testing. This, however, conflicts with the present findings. It also highlights the issue that differences in the types of knowledge test and the time when the tests are conducted may have important implications for knowledge-test performance.

Stanton et al. (1992) found the provision of a map in a HyperCard hypertext environment offered no benefits over the same system with no map provided in terms of their participants ability to produce a "cognitive map" of the system (i.e. hand draw a map of the structure of the system). They also found that participants who used a map reported significantly less control over the use of the system than participants in the no map condition. This is different to the results for part A in this experiment. However, this difference may have arisen due to differences in the systems used in Stanton et al's (1992) experiment and the present experiment. Based on the descriptions of their system given in Stanton et al.'s (1992) paper, two key disparities are apparent. Firstly their system was not simply based on embedded links in the body of the text. Links were also provided outside the main block of text. Secondly, their map was neither constantly available, nor interactive, and their participants had to click on a map icon to access the map. Stanton et al. (1992) also pointed out that designers of hypertext systems should think about the appropriateness of navigation aids to the particular system, indicating conclusions from these types of studies may not be as simple as saying that one type of navigation aid is good for all types of systems.

Wenger and Payne (1994) also found that a graphical browser map used alongside an IBM HyperWIN hypertext system had no benefits in terms of recall or comprehension of the text compared to use of the system without the browser map. However, again differences in the system used, compared to the one in the present study, may account for the differences in the findings. The key difference appears to be that in Wenger and Payne's (1994) study the browser map was not constantly available and was non-interactive.

To date there appears to have been little experimental research into the effects on learning of creating maps when navigating in electronic texts, so comparisons are not possible. This also highlights the need for research in the area. There also appears to have been little or no research to date into the effects of using or creating maps compared to using embedded links on cognitive engagement or ownership. This means that the findings here have to be understood on their own and indicates that further research is needed.

5.4.1.2. Implications of Findings on Creating vs Using Maps

Considering the scope of this experiment in terms of the type of electronic text used, characteristics of the participants, the types of tasks employed during the use of the electronic texts, and measures of learning, four key implications about navigation aids and learning have been identified from the findings of part A.

1. Using a map to navigate has benefits in terms of cognitive engagement, feelings of ownership for learning, and knowledge construction as measured here, especially as compared to embedded links alone. It has been argued that this is because maps reduce extraneous cognitive load by providing a conceptual overview of the electronic text. Therefore, designers of educational electronic texts should consider employing maps as navigation aids. However, the mixed findings in previous research concerning the use of maps compared to embedded links only, indicates that the designers should carefully consider whether the map will be appropriate to the particular educational electronic text.
2. Allowing learners to create their own maps has little or negative effects on cognitive engagement, ownership and knowledge construction. It was argued that this was due to specific usability problems and factors associated with extraneous cognitive load. Accordingly, these types of navigation aids may be inappropriate for novice learners, such as the participants in this experiment, and designers should be aware of these issues. In particular, the finding that creating a map has no benefits in terms of feelings of control, as measured on the ownership questionnaire, has implications for our understanding of learning control. Designers and researchers should be aware of this.
3. Although embedded links were found to have positive effects on some cognitive engagement activities they also had negative effects on ownership and knowledge construction compared to using a map. Again problems of disorientation, confusion and cognitive load issues have been presented as explanations for this. Designers of educational electronic texts should take note of this.
4. Comparisons to previous research into the effects of maps compared to embedded links indicated that there were some differences with the findings of previous research. This highlights that the effects of navigation aids on learning are complex. Designers of educational electronic texts should be aware of this.

5.4.2 Part B – Creating vs Using A-Z Indices

5.4.2.1. Results Summary and Explanation for Findings

This section discusses findings from part B of this experiment according to each of the learning measures taken to test H_4-H_6. As in part A, potential explanations for these findings will be considered in terms of the post-hoc analyses of navigation behaviour and usability problems, as well as in terms of cognitive load theory. These explanations are not intended to be mutually exclusive. The relation of these findings to previous research is also discussed, and implications of the findings from part B are presented.

The main findings for participants who used an A-Z, those who created an A-Z and those that used embedded links in part B of this experiment were:

- ⇨ No significant differences between conditions were found for the cognitive engagement measures.
- ⇨ No significant differences between conditions were found for the ownership measures.
- ⇨ No significant differences between conditions were found for the knowledge construction measures, although, for aspect E of the transfer task there was a difference approaching significance and the participants in the using A-Z condition did better than the participants in the embedded links condition.

This does not support the predictions made in $H_4 - H_6$, and also differs from the findings of part A for using vs creating maps. The navigation behaviour measures were examined to provide further insight into why these findings occurred. Comparisons between using an A-Z and creating an A-Z revealed no significant differences for the number of operations, number of different pages visited, or for the percentage A-Z use and percentage link use. However, participants who created an A-Z showed a significantly higher back button usage than participants who used an A-Z. In part A we took higher back usage as indicative of higher cognitive load when it was accompanied by poorer performance on the learning measures. But, as already noted, there was little difference in these measures for part B, so there appeared to be little association between the back button usage and the learning measures in part B of this experiment.

Examination of usability problems revealed that there were no significant differences between instances of usability problems, unique problems and the total problem severity between the using A-Z, creating A-Z and embedded links conditions.

In terms of the types of usability problems experienced, focussing on problems in the understanding text category, the greatest number of problems was experienced by participants in the embedded links condition. In addition participants in the using A-Z and creating A-Z conditions also experienced problems in this category. In particular, participants in the creating A-Z condition experienced problems that were classified as "catastrophic" in the "Understanding Text" category. In this case participants completely misunderstood several concepts in the electronic text. However, overall, it does not appear that the differences in the types of usability problems were enough to influence performance on the learning measures, apart from perhaps the difference in performance on part B of the transfer task.

In terms of cognitive load, a tentative explanation for the fact that were few differences on the learning measures in part B is that there may have been no notable differences in extraneous cognitive load between the using A-Z, creating A-Z and embedded links conditions. The articulation involved in creating an A-Z was simple, and did not encourage the participants to think about the content of the electronic text or its conceptual structure. Alphabetical listings are common and the extraneous cognitive load of arranging pages into alphabetical order, compared to using an A-Z or using embedded links, may be low. The level of control offered in creating an A-Z was also likely to be similar to that offered in using an A-Z or embedded links, since the participants were required to arrange the pages in alphabetical order, rather than according to their own preferences. As such, there may have been little difference in the level of control offered to participants in these conditions.

Relation to Previous Research

Previous research has examined the effects of A-Z indices as compared to embedded links on navigation performance and found that an A-Z index can have positive effects (Gupta and Gramopadhye, 1995). However, there appears to have been little research on comparisons of A-Z indices and embedded links explicitly in terms of learning. In addition, it is apparent that there has been no research to date on the effects of using vs creating A-Z indices on learning. As such, this indicates that the results presented here can only be understood as a first examination of these issues and that further research is needed.

5.4.2.2. Implications of Findings

Considering the scope of this experiment in terms of the type of electronic text used, characteristics of the participants, the types of tasks employed during the use of the electronic texts, and measures of learning, one key implication has been identified from the findings of part B:

- Allowing learners to create their own A-Z indices has no significant effects on learning as measured here compared to using an A-Z index or using embedded links only. Designers and researchers of educational electronic texts should be aware of this issue.

5.4.3 Part C – Creating vs Using Contents Lists

5.4.3.1. Results Summary and Explanation for Findings

This section discusses findings from part C of this experiment according to each of the learning measures taken to test the hypotheses. Potential explanations for any differences between conditions are considered in terms of the post-hoc analyses of navigation behaviour and usability problems, as well as in terms of cognitive load theory. The relation of these findings to previous research is also discussed, and implications of the findings from part C are presented.

Cognitive Engagement

Overall, the findings on cognitive engagement for part C were not as predicted in H_4. The main findings were:

- ⇨ There were no significant differences across conditions for the cognitive engagement scores.
- ⇨ There were significant differences between conditions for Monitoring Understanding activities. Participants who used embedded links engaged in more of these activities than those who created a contents list.

This second finding indicates that in terms of Monitoring Understanding activities, using embedded links is more beneficial than creating a contents list. This is similar to findings for the creating map condition in part A; however unlike part A, using a contents list did not appear to have benefits over creating a contents list in terms of these cognitive engagement activities.

The navigation behaviour measures were examined for potential explanations for these findings. For the number of operations, participants in the creating contents condition performed a notably higher number of operations than participants in the using contents condition. However, since the embedded links condition also showed a high number of operations, this measure does not explain the findings on the cognitive engagement activities for participants in the embedded links condition compared to those who created a contents list.

There were no significant differences for the number of different pages visited for part C. As discussed in relation to part A, the embedded links condition was not included in comparisons of link, back button and contents list usage because the link and back button usage would necessarily be higher in this condition. Analyses of link, back and contents list usage, therefore, cannot be used to explain differences in cognitive engagement activities between the creating contents and embedded links conditions. As such, the usability problem measures were then examined for potential explanations of the findings.

Analyses of the number of instances, unique problems, and total problem severity revealed no significant differences between conditions. The types of usability problems in the creating contents condition compared to those in the embedded links condition were then examined. Problems associated with navigation efficiency and specific problems related to creating, navigating and interacting with the contents list were the most dominant problems for the creating contents list condition. While participants in the embedded links condition did experience some problems of navigation efficiency, they also experienced a greater number of problems related to understanding the content of the electronic text. Consequently, it appeared that the usability problems could give no obvious explanation for the differences on the cognitive engagement activities found between the creating contents and embedded links conditions.

Another explanation for the finding that embedded links led to more Monitoring Understanding activities was examined in relation to the proposed benefits of embedded links for engagement. As discussed in relation to part A, embedded links have proposed benefits in terms of exploration (Collier, 1987), being engaging to use (Jonnasen, 1989), their use of a form of representation similar to the human mind (Delany and Gilbert, 1991), and encouraging deeper processing (Niederhauser et al., 2000). One might think that participants in the creating contents condition should also experience these benefits, since at least initially their navigation was primarily through the embedded links until their contents list was built up. However, examination of the link, back and contents list usage revealed that the participants in the creating contents condition on average used each of the available navigation aids, the contents list, back button and links, roughly in a ratio of 1:1:1, respectively. Therefore, participants who created a contents list did not predominantly use the embedded links to navigate. Also, the provision of facilities to create a contents list may have imposed extraneous cognitive load on participants in that condition compared to those who simply used embedded links, so the participants who created a contents list did not see the benefits of the embedded links for cognitive engagement. This may provide a tentative explanation for the embedded links participants engaging in more Monitoring Understanding activities than those who created contents lists.

Ownership

Findings on feelings of ownership for learning were not as predicted in H_5. The main findings were:

- ⇨ Using a contents list led to significantly higher feelings of control for learning than embedded links, whereas creating a contents list led to no significant benefits over embedded links in terms of control.
- ⇨ There were no significant differences for total ownership and the responsibility and value factors as measured by the questionnaire.

As with part A, the finding that using a contents list led to higher feelings of control than embedded links, whereas creating a contents list did not, was somewhat surprising. One might expect that allowing a learner to create their own contents list offers them more control over their learning with the electronic texts since they are able to create the list according to their own preferences. Again, this has implications for our understanding of learner control, and highlights the fact that the control perceived by learners may be different from the apparent level of control offered by the navigation.

The navigation behaviour measures were looked to for explanation of this finding. As mentioned in the previous section, the participants who created a contents list on average performed significantly more operations than participants in the using contents condition, and participants who used embedded links fell between these two extremes for the number of operations. Although this finding does not account for the lower feelings of control in the embedded links condition, it highlights that the lowest number of operations in the using contents list condition were also associated with the highest feelings of control.

Explanations for the differences on the control factor were also sought from the usability problem measures. No significant differences were found for the number of instances, unique problems and total problem severity, therefore, additional explanations were sought by examination of the types of usability problems experienced in the using contents and embedded links conditions. Comparisons of the using contents and embedded links conditions revealed that participants who used embedded links experienced more problems related to understanding the text than any other condition. They also experienced slightly more problems related to disorientation and making predictions about the navigation aids than participants in the using contents condition. However, it might be expected that problems with the efficiency of navigation are also important for feelings of control, yet, participants in the using contents condition showed similar levels of these types of problems to those in the embedded links condition. From this it appears that the types of usability problems do not reveal any definite explanations for the differences in feelings of control.

Knowledge Construction

The findings on knowledge construction were not as predicted in H_6. The main findings were:

- ⇨ Participants in the using contents list condition performed significantly better than those in the embedded links condition for the total transfer task marks, as well as aspects B, E and F.
- ⇨ Participants in the using contents list and creating contents list conditions produced significantly more detailed hand-drawn concept maps than participants in the embedded links condition.
- ⇨ Participants in the using contents list condition produced significantly higher quality concept maps than those in the embedded links condition.

Overall, these findings are similar to those found for using and creating maps in part A and imply that, in terms of knowledge construction, using a contents list is particularly beneficial to knowledge construction as measured here, whereas embedded links are not.

The navigation measures were examined for potential explanations of this finding. This revealed that the pattern of results for the transfer task performance was almost the opposite of the pattern for the number of operations. As discussed previously, the number of operations was low for the using contents list condition, whereas it was relatively high for the embedded links condition. Conversely, performance on the transfer task was high in the using contents list condition and low in the embedded links condition. This indicates that there may be a negative relationship between the number of operations and learning.

The usability problem measures were then examined for potential explanations of the knowledge construction findings in part C. However, as discussed earlier there were no differences on the number of instances of usability problems, unique usability problems and total severity of usability problems between conditions in part C. Nonetheless, in terms of the types of usability problems experienced, the fact that participants in the embedded links condition experienced more problems related to understanding the content of the electronic text, compared to both the using contents list and creating contents list conditions, may provide some explanation for the findings on the knowledge construction measures. The higher number of understanding text problems in the embedded links condition may have been detrimental to performance on the knowledge construction measures as compared to the using contents list condition.

Finally, similar to part A, in terms of cognitive load theory an explanation for the differences on the knowledge construction measures might be that using embedded links was associated with a higher level of extraneous cognitive load than using a contents list. In the embedded links condition extraneous cognitive load may have arisen when participants had to decide where to go and what to read next, as well as having to work out how to get there. In the using contents list condition, on the other hand, an overview of the electronic text was provided and participants could use this to access pages in the electronic text. In addition, guidance was given as to the conceptual structure of the electronic text by indentations on the contents list, and since the list read from top to bottom, guidance about an ideal order in which to visit pages was also given. This may have reduced extraneous cognitive load, and thereby led to improved performance on the knowledge construction measures.

Relation to Previous Research

The findings for part C presented here are somewhat similar to comparisons of using contents lists versus embedded links in McDonald and Stevenson (1999) discussed in chapter 2. They found that in terms of performance on a node recall test, participants who used a contents list as a navigation aid performed better than participants who used plain hypertext (embedded links only). However, in terms of factual knowledge questions regarding the content of the electronic text, participants who used the contents list showed no differences in performance to those that used plain hypertext. In this respect McDonald and Stevenson's (1999) findings differ from those in the present study. This may be accounted for by differences between the systems used in the two studies. Principally, the contents list provided in McDonald and Stevenson's (1999) study was non-interactive, and in addition the tests of learning used in their study only concentrated on factual knowledge. The learning measures employed in this experiment, on the other hand, aimed to assess deeper learning. These differences in findings indicate the importance of the types of systems used and measures of learning in terms of interpreting the results of such studies.

As with comparisons of using versus creating maps and A-Z indices, there appears to have been little experimental research into the effects of creating contents lists when navigating in electronic texts on learning, so comparisons with previous research are not possible. Again, this highlights the need for further research in the area. In addition, the lack of previous research into the effects of navigation aids on ownership and knowledge construction highlights the need for further research into the effects on these aspects of learning.

5.4.3.2. Implications of Findings for Creating vs. Using Contents Lists

Considering the scope of this experiment in terms of the type of electronic text used, characteristics of the participants, the types of tasks employed during the use of the electronic text, and measures of learning, four key implications were identified from the findings of part C.

1. Using a contents list has benefits in terms of feelings of control for learning and knowledge construction as compared to embedded links. It has been argued that this is due to the overview, guidance and conceptual information provided by the contents list, thereby reducing extraneous cognitive load. Therefore, designers of educational electronic texts should consider employing contents lists as navigation aids.
2. Creating a contents list offers no benefits for any of the learning measures over embedded links. The lack of a difference on feelings of control in particular has implications for our understanding of learner control. Designers and researchers of educational electronic texts should be aware of this issue.
3. Although embedded links have benefits in terms of some cognitive engagement activities compared to creating a contents list, knowledge construction and feelings of control was lower for participants who used embedded links compared to those who used contents lists. This has been explained in terms of problems understanding the electronic text content and extraneous cognitive load associated with the embedded links condition compared to the using contents condition.
4. Comparisons of these findings to those in previous research on the effects of contents lists vs. embedded links indicated that there were some differences in the findings. This highlights that the effects of navigation aids on learning are complex. Designers of educational electronic texts should be aware of this.

5.4.4 General Discussion and Conclusions

Overall, the findings from parts A, B and C of this experiment indicate that creating navigation aids has little or negative effects on learning as measured here. This is contrary to the predictions made in H_4-H_6. Considering each part of this experiment in turn it is apparent from part A that creating maps generally has a negative impact on learning compared to using maps and embedded links, whereas using a map tended to have positive effects on learning. In part B, creating A-Z indices, on the other hand, had little effect on learning as compared to using A-Zs and using embedded links. In part C, creating contents lists had no significant impact on learning compared to using contents lists or embedded links, but using a contents list did have benefits over embedded links in terms of learning. In parts A and C, embedded links tended to be beneficial to some aspects of engagement, but had a negative impact on aspects of ownership and knowledge construction.

Comparisons with previous research emphasised methodological implications about the types of system used and the types of knowledge tests used. This suggested that for any implications taken from the three parts of this experiment, particularly in relation to the types of navigation aids that should be employed in educational electronic texts, designers should also carefully consider the attributes of the system in which the navigation aid will be employed. This is discussed further in chapter 7.

The findings of parts A, B and C presented here led to the conclusion that in this experiment creating navigation aids did not benefit learning as compared to using existing navigation aids or embedded links. It has been argued that this is due to specific usability problems and the cognitive load associated with creating navigation aids. Hence, designers of educational electronic texts should not assume that the articulation and additional learner control offered by creating navigation aids benefits learning with electronic texts.

The next chapter examines extends the work in this chapter and examines whether allowing learners to adapt maps as navigation aids in educational electronic texts has benefits for learning by allowing articulation and learner control without increasing cognitive load.

6 Experiment 3: Adapting Maps in Educational Electronic Texts

This chapter extends the work in chapter 5 and presents an experimental investigation into the effects on learning of allowing learners to adapt maps as compared to using or creating maps.

6.1 Introduction

Based on the framework of constructivism and navigation, it was hypothesised that allowing learners to create their own navigation aids in educational electronic texts would have benefits for learning, and this was tested in experiment 2. Two key reasons were put forward for this hypothesis in chapters 3 and 5. Firstly, creating navigation aids allows the learner to articulate their ideas about the electronic text content, and secondly it affords them control over their learning. However, these benefits were not found in experiment 2; the findings revealed that creating navigation aids actually had little or negative impact on learning, and one possible explanation for this was discussed in terms of cognitive load. This chapter presents an experimental study that extends the work in experiment 2 and examines the effects of adapting navigation aids on cognitive load and learning.

Adapting navigation aids differs from allowing the learner to create navigation aids in that they do not have to construct the entire navigation aid themselves; the learner is already given an existing navigation aid which they can adapt by changing its content, structure and layout. It also differs from simply using a navigation aid in that the learner is able to make these changes to the navigation aid. In this thesis it is proposed that adapting existing aggregate navigation aids can ameliorate the problems of cognitive load because the learner is provided with an initial overview of the electronic text. As discussed in chapters 2, 4, and 5, navigation aids that provide an overview of an electronic text may reduce cognitive load (Boechler, 2001; Brunstein et al., 2004; McDonald and Stevenson, 1999) and the learner does not have to allocate cognitive resources to constructing a mental overview of the electronic text content, as they do when creating navigation aids or using embedded links alone. Allowing learners to adapt navigation aids is predicted to have positive effects on learning, because it allows articulation and control, without increasing cognitive load.

The work in this chapter contributes towards **objective 3** of the thesis, *"To empirically test hypotheses that were motivated by the framework of constructivism and navigation"*. In order to investigate the effects of adapting navigation aids on learning the following hypotheses were framed:

> **H_7** – Learners who *adapt* existing navigation aids will feel higher levels of ownership for their learning with an electronic text than learners who *create* their own navigation aids, learners who *use* existing navigation aids and learners who use embedded links.

H_8 – Learners who *adapt* existing navigation aids will develop higher quality knowledge about the content of an electronic text than learners who *create* their own navigation aids, learners who *use* existing navigation aids, and learners who use embedded links.

There is also a third hypothesis implicit in the motivation for experiment 3:

H_9 – Learners who *adapt* existing navigation aids will feel lower cognitive load than learners who *create* their own navigation aids and learners who use embedded links.

H_9 predicts that adapting navigation aids reduces cognitive load as compared to creating navigation aids and using embedded links. However, it should be noted that it is not predicted that adapting navigation aids reduces cognitive load as compared to using navigation aids, since learners who use an existing navigation aid are also provided with an overview of the electronic text.

This chapter describes an experimental investigation designed to test H_7, H_8 and H_9. In particular, this chapter focuses on the effects of *adapting* versus *creating* versus *using* **maps** for navigation. The effects of maps are selected for further investigation here, not only because of the differences that were revealed between creating and using maps in experiment 2, but also, because of the interest in maps as navigation aids and the use of maps as educational tools in recent research literature. For example, as discussed in chapter 2, there have been several experimental studies that have evaluated the effects of maps on learning with electronic texts (e.g. McDonald and Stevenson, 1999; Stanton et al. 1992; Wenger and Payne, 1994; Puntambekar et al., 2003) and there have also been recent developments in navigation aids for educational electronic texts that include maps (Elkund et al. 1999; Okada and Zeiliger, 2003; Zeiliger, 1996).

As in experiments 1 and 2, a constructivist perspective is taken in the way that learning is assessed here, and the effects of adapting maps are considered in terms of feelings of ownership as well as knowledge construction. The usability of the electronic text is investigated to explore potential explanations for findings on the learning and cognitive load measures. Post-hoc analyses of the navigation maps created and adapted by the participants in this experiment are also presented so that any potential explanations for findings on the learning measures can be considered.

It should be noted that there are other key differences between this experiment and experiments 1 and 2. Firstly, cognitive engagement is not evaluated here, since it is not directly related to the aims of this experiment. Secondly, no data is presented concerning the participants' navigation behaviour due to technical problems with the Nestor Navigator log files. Thirdly, there are some differences in the method used. Details of the differences in the method, and the reasons behind them, are described in the next section.

At the end of this chapter, in contribution to thesis **objective 4**,*"To distil the findings of the empirical investigations into a set of implications to inform designers and researchers of educational electronic texts"*, the key implications of the findings from experiment 3 are identified.

6.2 Method

In this experiment, learners used the electronic text on usability evaluation with the facilities to adapt, create or use a map, or with embedded links only. They were initially tested for their existing knowledge of the subject described in the electronic text. Whilst using the electronic text, they were given a task where they had to use the information in the electronic text to solve a problem in a given scenario. Afterwards their feelings of ownership for their learning, their ratings of cognitive load and usability, and their knowledge construction were tested. The navigation maps that the learners created and adapted were also analysed post-hoc.

For the most part, the method used in this experiment was very similar to that in experiments 1 and 2. However, it should be noted that there are two important differences in the method in this experiment as compared to experiments 1 and 2. Firstly, the experimental setting was different in that it took place in a computer lab where up to six learners participated in the experiment at any one time. In experiments 1 and 2, learners participated in the experiments individually. Secondly, the time allocated for the experimental sessions was shorter in experiment 3, in order to encourage learners to take part in the experiment. Accordingly, the training task, the task as they used the electronic text, the written transfer task, and the concept mapping task were all adapted to fit the new experimental setting and adjusted to account for the time constraints. The details of the participants, measures and experimental tasks used in this experiment are described here.

6.2.1 Participants

Thirty-two students took part in experiment 3. These were different people to those who participated in experiments 1 and 2. They were registered on an introductory HCI course in the autumn term 2003, or were interested in registering on an introductory HCI course in the spring term 2004. The participants had all attended an introductory HCI session, but had not yet attended a lecture on usability evaluation (the topic presented in the electronic text). Table 6.1 shows a breakdown of the participants' demographic characteristics.

Age Range		Gender		Undergraduate/ Postgraduate		Computer Experience		WWW Experience		WWW Use	
18-29yrs.	24	Female	14	Undergrad.	12	< 1 yr.	0	< 1 yr.	0	Daily	30
30-39yrs.	5	Male	18	Postgrad.	20	1-3 yrs.	2	1-3 yrs.	6	Weekly	2
40-49yrs.	3	-	-	-	-	4-5 yrs.	2	4-5 yrs.	9	Monthly	0
50+ yrs.	0	-	-	-	-	5+ yrs.	28	5+ yrs.	17	Rarely	0

Table 6.1. The number of participants in each demographic category, and the number in each category for computer and web experience and web use.

6.2.2 Equipment and Materials

Participants used PCs running an Intel Pentium 4 processor and 512MB RAM with a 17" monitor, keyboard and mouse. They used the Nestor Navigator browser to access and navigate the same electronic text on usability evaluation as used in experiments 1 and 2.

6.2.3 Design and Procedure

A between-subjects design was employed and participants were randomly assigned to experimental conditions. The independent variable was the type of navigation provided and the four experimental conditions were:

1. using a map (+ embedded links)
2. creating a map (+ embedded links)
3. adapting a map (+ embedded links)
4. embedded links

There were eight participants in each condition. The navigation aids in conditions 1, 2 and 4 (using a map, creating a map and embedded links) were the same as in part A of experiment 2 except that they also included a forward button. In condition 3 (adapting a map) participants were initially provided with a map showing the page titles for all twenty-three pages in the electronic text displayed in a left-hand window (the map was identical to that in the using map condition) which they could use to access pages in the electronic text. They could also access pages through embedded links within the text and/or by using a back button and/or a forward button. New links appeared on the map every time an embedded link was traversed that was not already represented on the map. In addition, participants could add and delete links and pages on the map as well as rearrange the map. In this way the participants could adapt the map according to their own preferences to produce their own customised map (see figure 6.1). In the adapting and creating map conditions, the node for the page that was currently being displayed was shown in red (rather than the standard blue). It should be noted that in the using map condition the map gave no indication of which page was currently being displayed (this is a feature of Nestor Navigator).

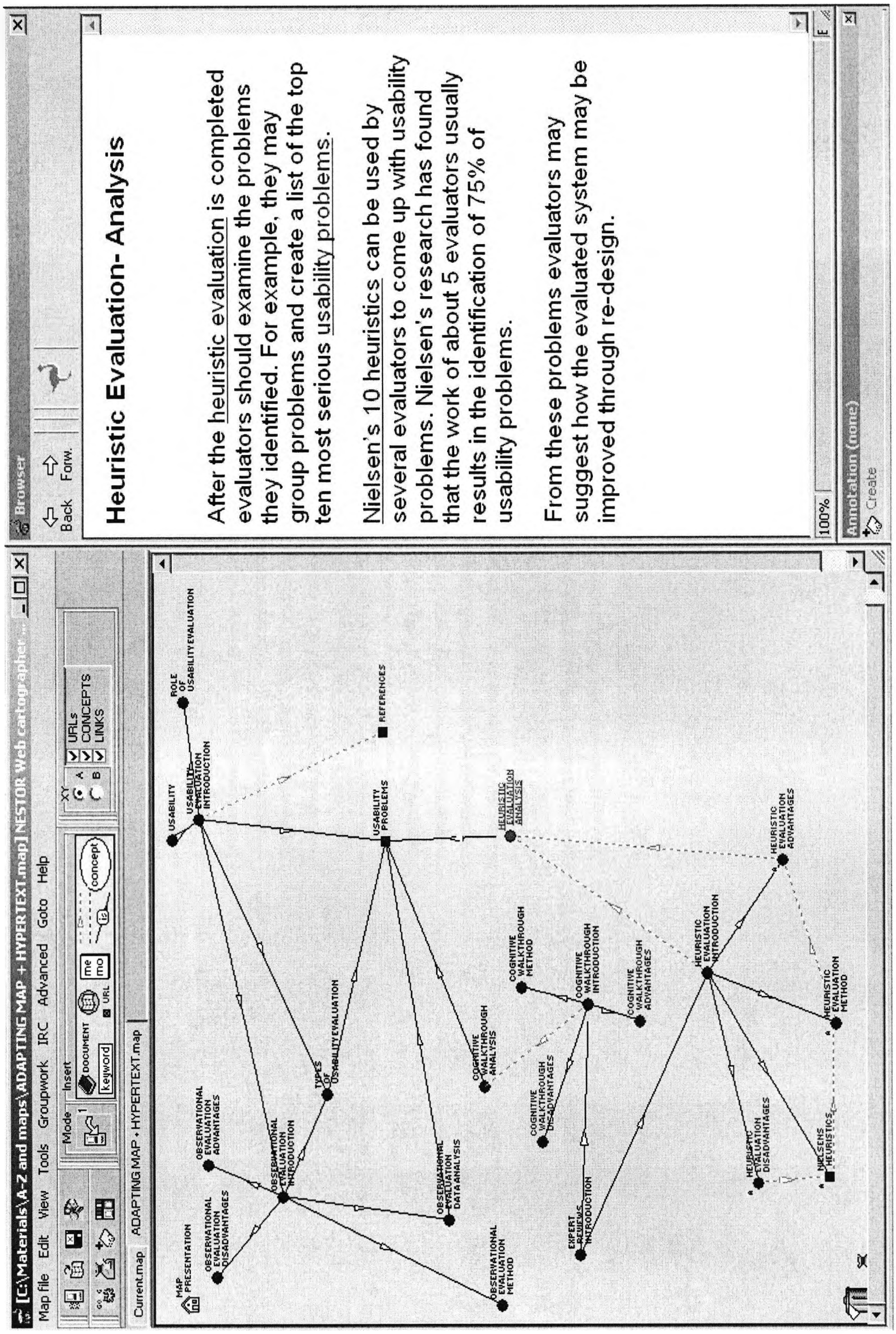

Figure 6.1. The adapting map condition (after adaptations have been made).

The experiment was conducted in group sessions in a computer lab with up to six participants at a time. The aim of this was to place this experiment in a realistic educational context where groups of students undertake individual tasks in a computer lab, similar to the setting of a tutorial session. Each experimental session lasted around 1 ½ hours. It should be noted that this was less time than the experimental sessions in experiments 1 and 2. The experimental session was made shorter in experiment 3 to make it easier to recruit participants and accordingly the time allocated to each part of the experiment was shortened. As in experiments 1 and 2, an experimental script was used to ensure that the verbal instructions given to participants were consistent (see appendix 6.1). There were seven parts to the experimental procedure. The details of each of the measures taken are described in sections 6.2.3.1 and 6.2.3.2.

1. Upon arrival participants were given introductory information about the general aims of the study and completed a consent form.
2. Demographic information about the participants was collected and a pre-test was administered. This was the same as in experiments 1 and 2 (see appendix 4.3).
3. A ten-minute training task was undertaken using sample materials on the American Museum in Britain to familiarise the participant with Nestor Navigator and the navigation they would be using (see appendix 6.2 for the training task sheets). This training task was similar to that in experiments 1 and 2, but was adjusted to fit the experimental setting of experiment 3. Because up to six participants were taking part at any one time, the experimenter could not give as much attention to each participant as had been done in experiments 1 and 2 and participants had to undertake the training task independently. In experiments 1 and 2 the experimenter had checked verbally whether participants were satisfied that they could use each aspect of the interface. In experiment 3, the task information sheet was adapted so that participants could tick off a list of the interface features to show that they were happy with using them. The experimenter then simply checked whether they had ticked all the boxes on the list.
4. Participants were given the usability evaluation electronic text, and were asked to use it to solve a usability evaluation problem. They were given the same scenario as in experiments 1 and 2 describing a usability evaluation for a music shop website that included details of a budget, timescales and access to users. They were then asked to use the electronic text to choose an evaluation technique or combination of techniques for this setting. However, there were some differences in this task as compared to experiments 1 and 2 so that it would fit in with the experimental situation for experiment 3. Participants were asked to record their decision on paper and to give two reasons why they thought their recommended technique(s) were appropriate and two reasons why they thought the other techniques presented in the

text were inappropriate (see appendix 6.3 for the task sheets). In experiments 1 and 2, the participants had been asked to think-aloud and gave their decision verbally. Given that the participants did not have to think-aloud in this experiment, which has been documented to extend task completion times (Ericsson and Simon, 1984), the allocated time for this task was shorter than in experiments 1 and 2. In this experiment the participants had up to thirty minutes to complete this task. Participants in the creating and adapting map conditions were asked to create or adapt their maps as part of this task.

5. The electronic text was then closed and participants were asked to complete a questionnaire with three sections: 1) feelings of ownership for learning; 2) the usability of the electronic text; 3) the level of cognitive load they experienced whilst using the electronic text (see appendix 6.4 for a copy of the questionnaire).
6. The participants then completed the written transfer task. This was similar to that in experiments 1 and 2, in that the scenario given to participants was the same, but the format of the task was adjusted to fit with the experimental setting in experiment 3 (see appendix 6.5 for the task sheet). In this experiment, to fit with the the task that participants performed as they used the electronic text, they were asked to respond to specific questions to guide their written answers (see section 6.2.3.1 for more details). Participants were also given slightly less time to complete this task compared to experiments 1 and 2; they were given up to twenty minutes to complete this task, as compared to the thirty minutes given in experiments 1 and 2.
7. The participants completed the concept mapping task (see appendix 4.9 for the task instructions). This was the same as in experiments 1 and 2 except that they were given up to five minutes to complete this task, as compared to the ten minutes offered in experiments 1 and 2.

After completion of all experimental tasks, the aims of the experiment were explained to each participant and they were given the choice of receiving copies of any publications or reports on the experimental findings.

6.2.3.1. Learning Measures

As in experiments 1 and 2, the pre-test was employed as a control measure to ensure that participants all had the same level of background knowledge of the content of the electronic text. Again, this consisted of the same seven questions testing participants' knowledge of usability evaluation, the topic presented in the electronic text (see appendix 4.3).

There were two dependent variables employed to test $H_7$and H_8 feelings of ownership for learning and knowledge construction. Ownership was measured using the ownership questionnaire described in experiment 1 in chapter 4 (see appendix 6.4).

Knowledge construction was measured in two ways: performance on a written transfer task and performance on a concept mapping task. As mentioned above, the written transfer task was adjusted to fit in with the experimental setting in this experiment (see appendix 6.5). Participants were given the same usability evaluation scenario as in the transfer task in experiments 1 and 2, in which they were asked to choose a usability evaluation technique to evaluate memo software on a mobile phone. However, in this experiment they were given room on their task sheet to respond to three questions:

- "Briefly explain what usability evaluation is";
- "Give brief details of each of the techniques presented in the materials and the advantages/disadvantages of using each one to evaluate memo software";
- "Give brief details of your recommended usability evaluation technique for evaluating memo software and say why you think it is the best technique".

Again, the aim of this task was to assess how well participants could apply information they had gathered from the electronic text in a new situation. The instructions for the concept-mapping task were the same as that in experiments 1 and 2 (see appendix 4.9).

Details of the analyses of these measures are described in section 6.3.1.

6.2.3.2. Cognitive Load

To test H_9, the questionnaire given to participants after they used the electronic text included five statements on cognitive load (see appendix 6.4). These were positively and negatively worded and related to the amount of mental effort participants had to put into using the electronic texts. The questions were developed based on Sweller's (1988) definition of cognitive load as the burden a particular task imposes on the cognitive system. As suggested by Kalyuga et al. (1998), subjective ratings of mental effort are useful because they are easy to implement and do not influence primary task performance, as other methods do, such as dual tasks. Subjective ratings of cognitive load have also been measured by questionnaires in other studies of cognitive load in educational tasks (Paas and van Merrienboer, 1993; Paas et al., 1994; Eveland and Dunwoody, 2001). In this experiment participants were asked to rate their agreement with these statements on a five-point Likert scale from "Strongly Disagree" to "Strongly Agree". Details of the analysis of this section of the questionnaire are described in section 6.3.2.

6.2.3.3. Usability and Navigation Map Measures

The questionnaire given to participants included fourteen statements on usability (see appendix 6.4). This questionnaire measure was used because as the participants did not think-aloud during this experiment any usability problems they experienced while using the electronic text could not be detected. This was an exploratory measure to examine any potential explanations for findings on the cognitive load and learning measures. The usability sub-section of the questionnaire consisted of positively and negatively worded statements on usability and there were a total of fourteen statements. These statements were developed to measure key usability issues: ease of use, effectiveness, efficiency, ease of learning, ease of remembering, error free usage and satisfaction and enjoyment. The participants were asked to rate their responses to each statement on a five-point Likert scale from "Strongly Disagree" to "Strongly Agree". Details of the analysis of this section of the questionnaire are described in section 6.3.3.

The navigation maps produced by participants in the adapting and creating map conditions were saved for analysis. The purpose of collecting this information was to explore potential explanations for differences between conditions on the cognitive load and learning measures. To this end, there were two further aims: firstly, to see how the maps which participants created and adapted differed from those that were provided in the using map condition; secondly, to determine the extent to which participants in the adapting map condition adapted their maps. Details of how these maps were analysed are described in section 6.3.3.

6.3 Analysis

This section presents the analyses performed on the data collected in experiment 3. Steps taken to ensure the reliability and validity of measures are also discussed.

6.3.1 Learning Measures

This section presents analyses for the pre-test, ownership and knowledge construction measures taken to test H_7 and H_8.

6.3.1.1. Pre-test

The pre-test was marked by the author as in experiment 1 (see appendix 4.10 for the marking scheme). To check the reliability and validity of the marking, an expert in usability evaluation external to this research independently marked a random sample of fifteen pre-tests taken from those completed by the thirty-two participants in experiment 3. A Spearman's rank correlation was employed to check how well the marks corresponded (see appendix 6.6 for details of the outputs of this analysis). This revealed a significant correlation between the two marks (rho(15)=0.880, p=0.000). This indicates that the marking was reliable and valid. For the results of the pre-test see section 6.4.1.

6.3.1.2. Ownership

An internal reliability analysis was conducted with the responses to the thirteen statements in the ownership section of the questionnaire from the thirty-two participants in experiment 3. This revealed a Cronbach's alpha of 0.80 indicating good internal reliability (see appendix 6.7).

Average total ownership and averages for the control, responsibility and value factors were calculated as in experiments 1 and 2. Kruskal-Wallis ANOVAs were employed to analyse differences across conditions and, where appropriate, non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. For the results of these analyses see section 6.4.1.

6.3.1.3. Knowledge Construction

The written transfer and concept mapping tasks were analysed to evaluate knowledge construction. It should be noted that, however, one participant in the embedded links condition did not undertake either the written transfer task or the concept mapping task because they complained of feeling ill and left the experiment after completing the questionnaire. In addition, another participant seemed to completely misunderstand the purpose of the concept-mapping task – they produced a concept map on the topic of human body parts. Therefore, the analysis of the transfer task consisted of data from thirty-one participants, and the analysis of concept-mapping task consisted of data from thirty participants.

The thirty-one written transfer tasks were marked by the author. They were marked out of five on each of the following aspects and an overall mark was calculated. The marks were then converted to percentages.

A. Explanation of usability evaluation
B. Brief details of each of the evaluation techniques presented in the electronic texts and their advantages/disadvantages in terms of using them for evaluating the mobile phone software in the given scenario
C. Brief details of the selected technique
D. Why that technique was chosen

See appendix 6.8 for the marking scheme. Again this was different from experiments 1 and 2 to fit in with the different format of the written transfer task.

To check the reliability and validity of the marking, an expert in usability evaluation external to this research second marked a random sample of fifteen written transfer tasks from those completed by the thirty-one participants who undertook this task in experiment 3. The second marker gave two of the written transfer tasks a notably higher mark than that given by the author. For one, the second marker gave a mark 30% higher than the mark given by the author, for the other the second marker gave a mark 35% higher than the author. The author discussed these marks with the second marker to determine the reasons behind these differences. It was noted that the second marker had marked these written transfer tasks according to their general quality, whereas the author had noted that although the two participants' written responses for the task were generally reasonable, they had not related their responses to the electronic text content very well. It appeared that the participants had used their general knowledge in their response, rather than using the information on usability evaluation in the electronic text. This discrepancy between the marks given by the author and those given by the second marker highlights the fact that the marking scheme was applied by the author in the context of how well participants responses to the written transfer task related to the electronic text content, rather than judging how good the responses were in general.

The marks for these two participants' written transfer tasks were not adjusted. They were simply excluded from the sample used to check the marking (but not from the remainder of the analysis) and for the remaining thirteen written transfer tasks in the sample, a Spearman's rank correlation was employed to check how well the two sets of marks corresponded (see appendix 6.9 for details of the outputs of this analysis). This revealed a significant correlation between the two sets of marks (rho(13)=0.845, p=0.000) and this suggests that overall the marking for the written transfer tasks was reliable and had good validity.

Kruskal-Wallis ANOVAs were employed to assess differences between conditions for all aspects that the transfer tasks were marked on, and where appropriate non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. For the results of these analyses see section 6.4.1.

As in experiments 1 and 2, the concept maps were given a quantitative mark (no. of nodes + no. of links represented) and a qualitative mark (the same marking scheme was used as in experiments 1 and 2, see appendix 4.18). To check the reliability and validity of the qualitative marks, a random sample of fifteen concept maps were taken from those produced by thirty of the participants in experiment 3, and were second marked by an expert on usability evaluation who was external to this project. A Spearman's rank statistic was calculated (see appendix 6.10 for details of the outputs of this analysis). This revealed a significant correlation between the two sets of marks (rho(15)=0.869, p=0.000). This indicates that the marking of the concept maps in this experiment was reliable and the mark scheme had good reliability and validity.

The quantitative marks were then analysed using a parametric ANOVA and Tukey post-hoc pair-wise comparison tests. The qualitative marks were analysed using a Kruskal-Wallis ANOVA and post-hoc pair-wise comparisons using the Siegal and Castellan (1988) method. For the results of these analyses see section 6.4.1.

6.3.2 Cognitive Load

To assess the quality of the statements in the cognitive load section of the questionnaire, an analysis of its internal reliability was performed. This was to ensure that all five statements in the section measured the same construct, in this case cognitive load. One statement was removed due to a low item-total correlation. Ratings for this statement showed low correlations with ratings on the other statements in the section indicating that it may be measuring a different construct. The Cronbach's alpha for the remaining four statements on cognitive load was 0.76 indicating good internal reliability (see appendix 6.11 for details of the output of this analysis). See box 6.1 for the statements from the usability and cognitive load sections that were used in subsequent analyses, and the statement that was removed from the cognitive load section. The total cognitive load rating for each participant was calculated by reversing the ratings for negatively worded statements (labelled "R" in 6.1) and adding together the ratings for the four statements (all statements were weighted equally), then dividing the sum total by four to give a total cognitive load rating out of 5. A higher rating indicated higher cognitive load.

For the total cognitive load ratings, Kruskal-Wallis ANOVAs were employed to analyse differences across conditions and, where appropriate, non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. For the results of these analyses see section 6.4.2.

Cognitive Load Statements

I had to put a lot of mental effort into understanding the information in the electronic texts.

I did not have to put a lot of mental effort into navigating the electronic texts. **[R]**

I had to put a lot of mental effort into working out where I was in the electronic texts.

I often felt that I had too many things to think about at once when using the electronic texts.

Usability Statements

The electronic texts were very easy to use.

I found it easy to work out how to access pages in the electronic text.

It will be difficult to remember information in the electronic texts. **[R]**

I had no problems using the electronic texts.

I found using the electronic texts enjoyable.

I would not use this type of electronic text again. **[R]**

I could easily work out where I wanted to go in the electronic texts.

I often had problems using the electronic texts. **[R]**

The navigation aids always did what I expected.

It was difficult to work out how to use the electronic texts. **[R]**

I found the using the electronic texts confusing. **[R]**

It was not easy to find the information I needed in the electronic texts. **[R]**

If I used the electronic texts again it would be easy to remember how to use them.

The electronic texts were very difficult to use. **[R]**

Removed Cognitive Load Statement

It took little mental effort to work out where I was in the electronic texts. **[R]**

Box 6.1. Statements that were in the Cognitive Load and Usability sections of the questionnaire and a removed statement. Reversed statements are marked by "R".

6.3.3 Usability and Navigation Map Measures

In this section the analysis of the usability and the analyses performed on the navigation maps are discussed.

6.3.3.1. Usability

In order to assess the quality of the statements in the usability section of the questionnaire, an analysis of its internal reliability was performed. This was to ensure that all fourteen statements in the section measured the same construct – usability. This included examination of ratings from all participants in experiment 3. The Cronbach's alpha was revealed to be 0.85 indicating that the usability section of the questionnaire had good internal reliability (see appendix 6.12 for details of the output of this analysis). The total usability rating for each participant was calculated by reversing the ratings for negatively worded statements (labelled "R" in 6.1) and adding together the ratings for the fourteen statements (all statements were weighted equally), then dividing the sum total by fourteen to give a total usability rating out of 5. A higher usability rating indicated better usability.

For the total usability ratings, Kruskal-Wallis ANOVAs were employed to analyse differences across conditions and, where appropriate, non-parametric tests for post-hoc pair-wise comparisons according to the Siegal and Castellan (1988) method were also used. For the results of these analyses see section 6.4.3.

6.3.3.2. Navigation Maps

The navigation maps that were created and adapted by participants in the creating map and adapting map conditions were compared to the map provided in the using map condition. The maps were analysed in terms of the number of nodes, number of navigation links (links representing actual embedded links between pages in the text) and the number of conceptual links (links representing conceptual relationships between pages where there is not necessarily a navigation link), as compared to the nodes, navigation links and conceptual links represented on the map given to participants in the using map condition. Since the number of nodes, navigation links and conceptual links for the using map condition were the same for every participant, the variance within that condition was zero for each of these measures, and would therefore differ from the variance within the other conditions. As such, parametric ANOVAs could not be employed to analyse this data because the homogeneity of variance assumption was not met. Accordingly, non-parametric Kruskal-Wallis ANOVAs and Siegel and Castellan (1988) post-hoc pair-wise comparison tests were used to assess differences between conditions for each of these measures. For the results of these analyses see section 6.4.3.

6.4 Results

The results of analyses of data collected in experiment 3 are presented here. Section 6.4.1 presents the results for the pre-test, ownership and knowledge construction measures taken to test H_7 and H_8. Section 6.4.2 presents the results for the cognitive load measures taken to test H_9. Section 6.4.3 presents the results for the usability, and navigation map measures. Statistical significance is set at the 0.05 level for all analyses. Graphs are only shown when statistically significant differences, borderline significant differences or differences approaching significance, are found and include error bars showing +1 standard error.

6.4.1 Learning Measures

6.4.1.1. Pre-test

The mean of the overall marks for the pre-test questions on usability evaluation was 16.59%. The standard deviation was 8.16. A check for overall marks of three standard deviations above the mean or more revealed that there were no extreme cases.

6.4.1.2. Ownership

The results of analyses for the ownership section of the questionnaire are summarised in table 6.2. See appendix 6.13 for further details of the outputs of these analyses.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total ownership scores (out of 5)	using map – 3.95; creating map – 3.68; adapting map – 4.25 embedded links – 3.80.	Non-significant.	N/A.
Control factor (out of 5)	using map – 4.40; creating map – 3.73; adapting map – 4.13 embedded links – 3.85. **(see figure 6.2)**	**Significant** (H(3,160)=11.991,p=0.007)	using map vs. embedded links; adapting map vs. embedded links.
Responsibility factor (out of 5)	using map – 3.65; creating map – 3.50; adapting map – 4.35 embedded links – 3.78. **(see figure 6.2)**	**Significant** (H(3,160)=18.192,p=0.000)	adapting map vs. using map; adapting map vs. creating map; adapting map vs. embedded links.
Value factor (out of 5)	using map – 4.05; creating map – 3.92; adapting map – 4.29 embedded links – 3.75.	Non-significant.	N/A.

Table 6.2. Results of analyses for ownership in experiment 3.

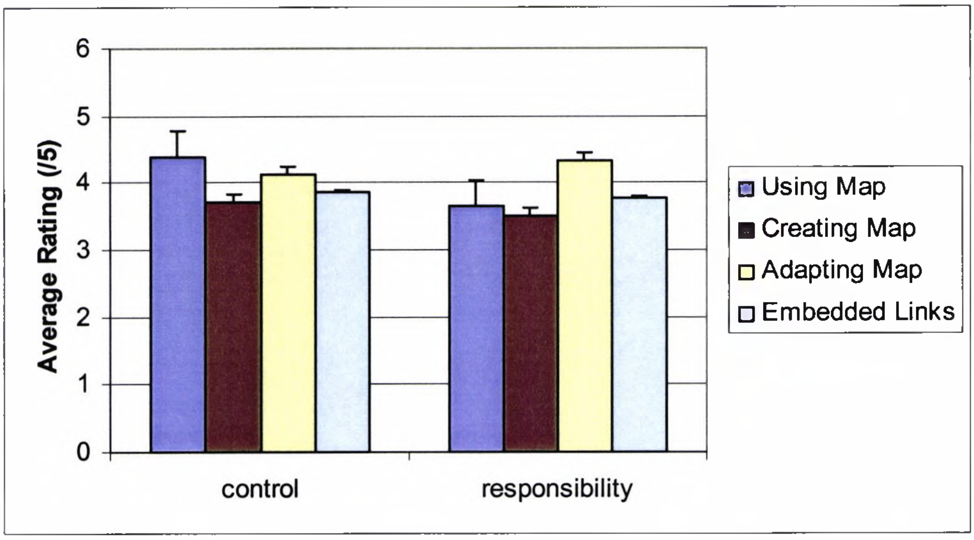

Figure 6.2. Average ratings (+1 standard error) on the control, responsibility factors in the ownership section for experiment 3.

6.4.1.3. Knowledge Construction

The results of the analyses for the written transfer task are summarised in table 6.3. For further details of the outputs of these analyses see appendix 6.14.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total transfer task mark (%)	using map – 31.89; creating map – 45.00; adapting map – 45.00; embedded links – 37.86.	Non-significant.	N/A.
A - Explanation of usability evaluation (%)	using map – 37.50; creating map – 55.00; adapting map – 27.50; embedded links – 48.57. **(see figure 6.3)**	**Significant** (H(3,31)=8.440, p=0.038)	No significant post-hoc tests.
B - Details of the evaluation techniques and their advantages/ disadvantages in terms of the given scenario (%)	using map – 35.00; creating map – 60.00; adapting map – 70.00; embedded links – 34.29. **(see figure 6.3)**	**Borderline significance** (H(3,31)=7.617, p=0.055)	No significant post-hoc tests.
C – Brief details of the selected technique (%)	using map – 22.50; creating map – 25.00; adapting map – 32.50; embedded links – 22.86.	Non-significant.	N/A.
D –Why that technique was chosen (%)	using map – 32.50; creating map – 40.00; adapting map – 50.00; embedded links – 45.71.	Non-significant.	N/A.

Table 6.3. Results of analyses for the written transfer task in experiment 3.

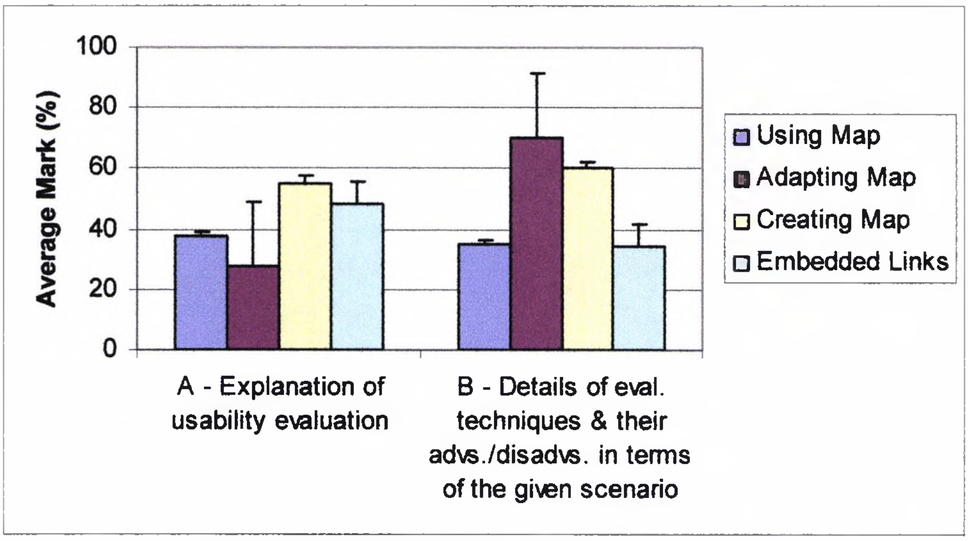

Figure 6.3. Average marks (+1 standard error) on aspects A and B of the written transfer task for experiment 3.

The results of the analyses for the concept-mapping task are summarised in table 6.4. For further details of the outputs of these analyses see appendix 6.15.

Analysis	Average for each condition	ANOVA	Significant post-hoc tests
Quantitative concept map mark	using map – 25.00; creating map – 30.13; adapting map – 25.29; embedded links – 25.57.	Parametric ANOVA non-significant.	N/A.
Qualitative concept map mark (%)	using map – 39.37; creating map – 40.94; adapting map – 43.57; embedded links – 40.36.	Kruskal-Wallis ANOVA non-significant	N/A.

Table 6.4. Results of analyses for the concept mapping task in experiment 3.

6.4.2 Cognitive Load

The results of the analyses for the responses to the cognitive load section of the questionnaire are summarised in table 6.6. For further details of the outputs of these analyses see appendix 6.16.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total Cognitive Load Rating (/5)	using map – 2.25; creating map – 2.09; adapting map – 1.94; embedded links – 3.03. **(see figure 6.4)**	**Significant** (H(3,32)=8.002, p=0.046)	embedded links vs. adapting map.

Table 6.5. Results of analyses for total cognitive load in experiment 3.

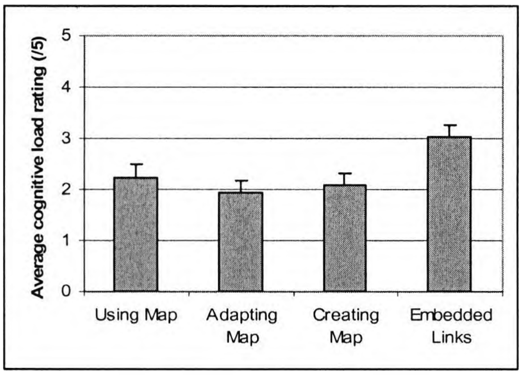

Figure 6.4. Average total cognitive load ratings (+1 standard error) for experiment 3.

6.4.3 Usability and Navigation Map Measures

6.4.3.1. Usability

The results of the analyses for the responses to the usability section of the questionnaire are summarised in table 6.6. For further details of the outputs of these analyses see appendix 6.17.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
Total Usability Rating (/5)	using map – 4.49; creating map – 4.38; adapting map – 4.59; embedded links – 3.99. **(see figure 6.5)**	**Significant** (H(3,32)=7.93, p=0.047)	**Significant:** adapting map vs. embedded links. **Approaching significance:** using map vs. embedded links (p<0.075)

Table 6.6. Results of analyses for total usability in experiment 3.

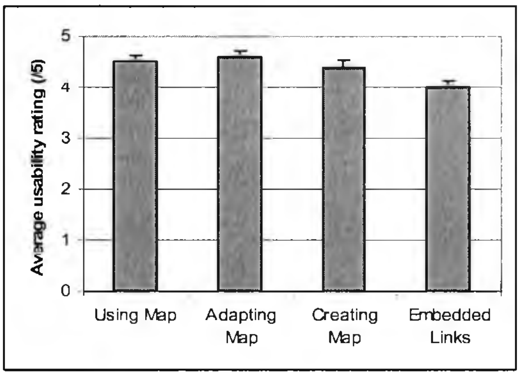

Figure 6.5. Average total usability ratings (+1 standard error) for experiment 3.

6.4.2.2. Navigation Maps

The results of the analyses of the created and adapted navigation maps produced by participants compared to the map provided in the using map condition are summarised in table 6.7. For further details of the outputs of these analyses see appendix 6.18.

Analysis	Average for each condition	Kruskal-Wallis ANOVA	Significant post-hoc tests
No. of Nodes (max 23)	using map – 23.00; creating map – 19.88; adapting map – 23.00. **(see figure 6.6)**	**Significant** (H(2,24)=14.930, p=0.001)	No significant post hoc tests.
No. of Navigation Links	using map – 19.00; creating map – 20.13; adapting map – 22.88.	Non-significant.	N/A.
No. of Conceptual Links	using map –3.00; creating map – 0.25; adapting map – 5.13. **(see figure 6.7)**	**Significant** (H(3,24)=18.23, p=0.000)	using map vs. creating map; adapting map vs. creating map.

Table 6.7. Results of analyses for the navigation maps in the adapting map and creating map conditions compared to the using map condition.

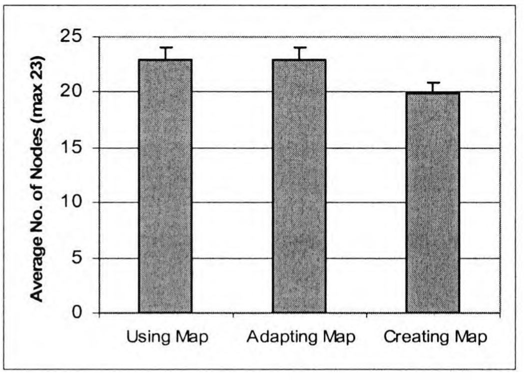

Figure 6.6. The average number of nodes (+ 1 standard error) represented in the navigation maps in the using map, adapting map and creating map conditions.

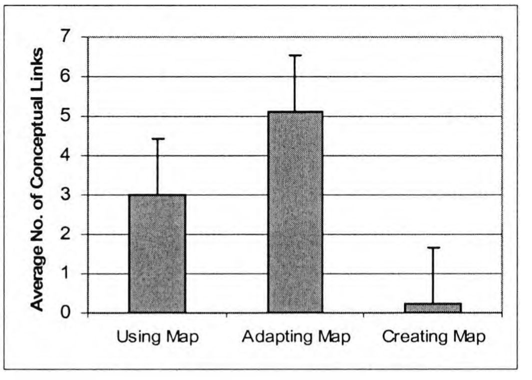

Figure 6.7. The average number of conceptual links (+ 1 standard error) represented in the navigation maps in the using map, adapting map and creating map conditions.

6.5 Discussion

Based on the findings of experiment 2, it was hypothesised that the learners who adapted existing navigation aids would feel higher levels of ownership and would develop higher quality knowledge constructions than learners who created their own navigation aids, used existing navigation aids for navigation, or simply used embedded links. It was also hypothesised that learners who adapted maps would feel lower cognitive load than learners who created maps or used embedded links. Overall, the results of experiment 3 indicate that allowing learners to adapt maps has benefits for some aspects of ownership, knowledge construction, and cognitive load. A secondary finding was that adapting maps also had benefits in terms of usability. The findings for the ownership, knowledge construction and cognitive load measures are discussed in turn. Finally, implications of the findings are identified and conclusions are drawn.

6.5.1 Results Summary and Explanations for Findings

In this section, potential explanations for differences between conditions for the learning measures and cognitive load measures are considered in light of the findings for the usability and navigation map measures. In addition the results are also discussed in relation to the findings from experiment 2 on creating navigation aids.

6.5.1.1. Ownership

The main findings from responses to the ownership questionnaire were:

- ⇨ Participants who adapted a map and participants who used a map reported significantly higher feelings of *control* than participants that used embedded links.
- ⇨ Participants who adapted a map reported significantly higher feelings of *responsibility* than any of the other three conditions.
- ⇨ There were no significant differences between conditions in terms of total ownership and the value factor.

The finding on the control factor indicates that both adapting a map and using a map had benefits in terms of feelings of control for learning with electronic texts, as compared to embedded links. Creating a map, on the other hand offered no benefits in terms of feelings of control. The finding on the responsibility factor indicates that in terms of feelings of responsibility for learning with electronic texts, adapting a map for navigation was beneficial as compared to using a map, creating a map or using embedded links.

In sum, the findings suggest that allowing learners to adapt existing maps has benefits in terms of their feelings of control and responsibility for learning. To explore potential explanations for these findings, the results for the usability and navigation map measures are considered here.

In terms of usability, there was a significant difference across conditions for the usability ratings, and it was revealed that participants in the adapting map condition tended to give significantly higher ratings than participants in the embedded links condition. The usability ratings for the using map and creating map conditions fell somewhere between these extremes. This suggests that the usability of the electronic text in the adapting map condition was greater than in the embedded links condition. This finding for usability shows a similar pattern to the control and responsibility results, suggesting that higher usability ratings were associated with higher control and responsibility.

Data on the navigation maps produced by participants was also examined for possible explanations of the findings on ownership. There were two aims: firstly, to see how the maps which participants created and adapted differed from those which were provided in the using map condition; secondly, to determine the extent to which participants in the adapting map condition adapted their maps. The findings revealed that the participants in the creating map condition had fewer nodes in their navigation maps than participants in the adapting map and using map conditions. This may suggest that the maps that participants created were less comprehensive than those in the using map and adapting map conditions. At first glance this finding could be taken to indicate that participants on average did not visit all the pages in the electronic text in the creating map condition. However, this is not necessarily the case. Participants in the creating map condition had the choice of deleting pages in the map, so it is impossible to tell from the maps whether they had deleted pages or whether they had simply not visited the pages. In addition, since no log file data was recorded it could not be determined whether this was the case. Participants in the adapting map condition were also offered the opportunity to delete pages from the map. However, similarly, it is impossible to determine from the navigation map measures whether they deleted pages, since all of the final navigation maps that were analysed in the adapting map condition contained twenty-three nodes. The participants could have deleted nodes from the map, but simply revisited them so that they reappeared on the map. The appropriateness of the navigation map measures will be discussed further in chapter 7.

The data on the navigation maps also revealed that the navigation maps in the using map and adapting map conditions had significantly more conceptual links (lines depicting a conceptual relationship between two pages, rather than representing an actual embedded link between two pages) than the navigation maps produced by participants in the creating map condition. There were conceptual links already present in the navigation map provided in the using map condition and the original navigation map provided in the adapting map condition. However, in the creating map and adapting map conditions participants had the choice of adding conceptual links to their maps. The fact that the maps produced by participants in the creating map condition contained so few conceptual links suggests that participants did not make much use of the facility to add these links. For the adapting map condition, compared to the using map condition, the results also showed that the participants in the adapting map condition did make use of the facility to add conceptual links. Participants in the adapting map condition produced navigation maps with significantly more conceptual links than there were in the original map they were provided with. This suggests that participants in the adapting map condition *did* actively adapt their navigation maps and this may have influenced their feelings of control and responsibility for their learning with the electronic texts. Similarly, it can be speculated that the fact that participants in the creating map condition did not add many conceptual links may have influenced the level to which they felt ownership for their learning with the electronic texts.

Overall, the results suggest that adapting maps for navigation has benefits for control and responsibility. A secondary finding is that adapting maps is also associated with higher ratings of usability, particularly in comparison with embedded links. Using a map and creating a map did not provide these benefits. These findings are somewhat in line with the predictions made in H_7.

6.5.1.2. Knowledge Construction

Knowledge construction was assessed through performance on the written transfer task and the concept mapping task. Overall, the findings were not always as predicted in H_8. The main findings were:

- ⇨ There were no significant differences between conditions for total marks on the written transfer task.
- ⇨ Participants in the creating map condition received the highest marks on *aspect A* ("Explanation of usability evaluation") of the transfer task and participants who adapted maps received the lowest marks. However, it should be noted that post-hoc tests did not indicate that this difference between the creating and adapting map conditions was significant.
- ⇨ Participants who adapted a map on average received the highest marks on *aspect B* ("Details of the evaluation techniques and their advantages/disadvantages in terms of the given scenario") of the transfer task, whereas participants who used embedded links received the lowest marks on this aspect of the task. Again, post-hoc tests did not indicate that this difference was significant.
- ⇨ There were no significant differences across conditions for the quantitative or qualitative concept map marks.

The finding for aspect A conflicts with the pattern of results predicted in H_8. However, the pattern for aspect B was more in line with the predictions of H_8. On first examination, these findings imply that in terms of the explanations of usability evaluation in the transfer task (aspect A), the creating map condition was particularly beneficial; whereas the adapting map condition led to the lowest performance. On the other hand, in terms of giving details of the evaluation techniques and relating their advantages and disadvantages to the task scenario (aspect B), then adapting a map was particularly good, whereas embedded links had negative effects. However, also looking at the non-significant results for aspects C and D of the transfer task, in terms of the participants' ability to give details of the selected technique (aspect C), and reasons for choosing that technique (aspect D), generally participants in the adapting map condition received the highest marks. So, for aspects B, C and D, adapting a map received the highest marks on average, which is in line with predictions. The pattern that occurred for aspect A is the exception. However, because the post-hoc tests did not reveal significant differences between conditions any differences between conditions for aspects A and B of the transfer task should be interpreted with caution. In addition, the non-significant results on aspects B, C and D should be treated with even greater caution. Overall the findings of the transfer task highlight the mixed effects of the different types of navigation on different aspects of knowledge construction.

Finally, for the concept-mapping task, the above finding suggests that in this experiment the differences between conditions had little effect on the participants' ability to produce a hand-drawn concept map on the content of the electronic text.

6.5.1.3. Cognitive Load

The findings on cognitive load were somewhat in line with the predictions made in H_9. The main finding was:

- ⇨ Participants in the embedded links condition reported significantly higher cognitive load than participants in the adapting map condition.

This finding suggests that allowing learners to adapt their own maps for navigation may reduce cognitive load as compared to using embedded links alone. As discussed in chapters 4 and 5, embedded links are thought to have incurred a high cognitive load when learners had to put effort into developing a mental overview of the electronic text, remembering where they had been, working out where they were, and deciding where they wanted to go next. In this thesis the adapting map condition is thought to have reduced cognitive load condition in two ways. Firstly, as argued in section 6.1, the map presented at the beginning of the experiment provided a conceptual overview, and this may have reduced cognitive load (Boechler, 2001; Brunstein et al., 2004). Secondly, the fact that the map changed in response to new navigations may have aided orientation since when new links were traversed they were represented on the map. This may have aided participants' ability to see where they were on the map and where they were going.

The pattern of findings for usability was examined for potential explanations for the findings on the cognitive load measures. The resulted showed that when the usability ratings were higher, as in the adapting map condition, the cognitive load ratings were lower. This highlights that there may be an inverse relationship between these two variables.

Looking at the navigation map data, however, the pattern of results did not appear to provide any explanations for the cognitive load data, and there appeared to be few similarities in the pattern of results for the two data sets.

6.5.1.4. Relation to Findings from Experiment 2

This experiment was not set up with the aim of directly comparing its results with those of experiment 2 since the methods and measures used were different. However, the using map, creating map and embedded links condition in part A of experiment 2 were similar to those conditions in this experiment. Therefore, it is useful to examine differences in findings because it highlights how aspects of the experimental set up can affect the results of the experiment. In comparison with the findings of part A of experiment 2, it was apparent in experiment 3 that using a map did not appear to have the significant benefits over embedded links in terms of feelings of ownership for learning and knowledge construction that were found in experiment 2. For ownership, although the findings for feelings of control were similar, the main differences occurred on the responsibility and value factors. In experiment 2, using a map led to higher feelings of responsibility than creating a map or embedded links. Using a map also led to higher value than creating a map. In experiment 3, in contrast, there was little difference in the responsibility and value ratings for participants in the using map, creating map and embedded links conditions. Only participants who adapted maps in experiment 3 reported higher feelings of responsibility than the other conditions, and there were no differences in feelings of value.

The key difference in the findings for knowledge construction between the two experiments was that in experiment 3 using a map was not found to have significant benefits over embedded links in terms of performance on aspects of the written transfer task and the concept-mapping task. Since the electronic text and the using map and embedded links conditions were the same in experiments 2 and 3, it appears that it may have been differences in the participants, the experimental tasks and measures, or the experimental setting that had some influence on these findings.

Examination of the demographic characteristics of participants in experiments 3 and those in part A of experiment 2 revealed no obvious differences between the two groups to explain the difference in the findings. Also since the level of prior knowledge was controlled in the pre-test, differences in the level of knowledge of the text content could not be used to explain differences in findings. However, the experimental setting was different in experiments 2 and 3. In experiment 3, groups of up to six participants took part at any one time, and the experiment took place in a computer lab. This was a quiet setting and participants were asked not to discuss the tasks with one another. The experimenter was present in the laboratory and monitored the participants' activities during the experiment in case they had any questions or problems. In experiment 2, on the other hand, participants took part in the study individually. In addition, since the participants were asked to think aloud during experiment 2, and many participants directed their verbalisations at the experimenter, this setting represented a different social context to that in experiment 3. The level of monitoring of the participants' activities was also higher here due to the one-on-one setting. Therefore, it may be that the different level of monitoring of participants' behaviour by the experimenter, and the different social contexts, provides some tentative explanation for the differences in findings between experiment 3 and part A of experiment 2. These differences in findings highlight the importance of context when evaluating the effects of different types of navigation on learning.

The experimental tasks and measures of knowledge construction were also different in experiment 3, and this may have impacted upon the findings. The fact that participants had less time in which to use the electronic texts (thirty minutes in experiment 3, compared to forty-five minutes in experiment 2) may have affected the results since participants were given less time to read and take in the information in the text. The fact that participants were not required to think-aloud while they used the electronic texts in experiment 3, whereas in experiment 2 they were, may also have influenced the way that participants cognitively processed the information in the electronic text. Participants were given slightly less time to complete the knowledge construction tasks in experiment 3 (twenty minutes as compared to thirty in experiment 2 for the transfer task, and five minutes compared to ten minutes in experiment 2 for the concept-mapping task). The way that they responded to the transfer task was also different in experiment 3, in that they were given set questions to guide their written responses to the task. This may have impacted the way that participants completed these tasks.

Overall, this discussion of the results of experiment 3 compared to experiment 2 in light of participant characteristics, the context, tasks and measures of the experiment, highlights the fact that the effects of navigation aids on learning are not clear. In contrast, the effects are complex and are likely to be influenced by the setting in which the electronic texts are used, the tasks they are used in, and the measures of learning. These issues will be discussed further in the future research section in chapter 7.

6.5.2 Implications of Findings

Considering the scope of this experiment in terms of the type of texts, type of tasks, characteristics of the participants and the experimental context, three key implications have been identified.

1. Allowing learners to adapt maps is beneficial to cognitive load, and feelings of control and responsibility for learning with electronic texts, particularly compared to embedded links. A secondary implication is that adapting maps is also beneficial in terms of usability, again in comparison to embedded links. Therefore, designers of electronic texts who want to encourage aspects of ownership and want to provide navigation aids with low cognitive load and good usability should consider providing this type of navigation.
2. There were mixed results in terms of the effects of adapting maps on knowledge construction. For example, on aspect A of the transfer task, creating maps was particularly beneficial, whereas adapting maps appeared to have negative effects. On aspect B, adapting maps was particularly beneficial; whereas embedded links were not beneficial. In other cases there were no significant effects of the type of navigation provided on knowledge construction. This indicates that different types of navigation aids may have different effects on different aspects of knowledge construction. Designers of educational electronic texts should be aware of these issues since it may imply that they have to consider trade-offs between one type of knowledge construction and another.
3. The fact that using maps was not found to be particularly beneficial to aspects of knowledge construction in experiment 3, whereas in part A of experiment 2 it was found to have benefits, highlights the importance of context, experimental tasks and measures of learning in terms of evaluating the effects of navigation on learning. Designers and researchers of educational electronic texts should be aware of these issues, since it suggests that what is beneficial in one context may not be beneficial in another context. This also highlights

that prescriptive design guidance may not be suitable for navigation in educational electronic texts.

6.5.3 Conclusions

Overall, the findings of experiment 3 suggest that allowing learners to adapt maps has benefits for their feelings of control and responsibility for their learning and reduces cognitive load. Adapting maps also has benefits in terms of usability. These findings are somewhat in line with the predictions made in H_7 and H_9, and suggest that for feelings of control and responsibility adapting maps may reduce cognitive load while at the same time allowing the benefits of additional learner control and articulation to be realised. However, in terms of knowledge construction and the predictions made in H_8, adapting maps did not offer any clear benefits over using maps, creating maps or embedded links.

7 Discussion and Conclusions

This chapter summarises the thesis research and concludes with a discussion of the overall implications and future research directions.

7.1 Summary of the Thesis

This thesis provides rich insight into the effects of navigation aids on learning with educational electronic texts within the broad context of constructivism. A detailed framework of constructivism and navigation was presented. This provided a basis for the formulation of implications and hypotheses about the effects of navigation aids on learning. Three in-depth controlled experiments were then described to test the hypotheses motivated by the framework.

In chapter 1, the scope, objectives and research methods were presented. Following from this, chapter 2 summarised previous research relevant to navigation and learning in electronic texts. This review highlighted three areas for investigation: the development of one detailed version of constructivism for use in this thesis; experimental research into new developments in navigation technology; and experiments that investigate learning from a constructivist perspective.

Chapters 3 to 6 presented the research in detail. This was structured according to the four objectives identified in chapter 1. The work in chapter 3 related to **objectives 1 and 2**: 1) *"To define a detailed framework of the essential features of constructivism and its implications for navigation aids in educational electronic texts"*; and 2) "*To use this framework to formulate hypotheses about the effects of different types of navigation aids on learning with electronic texts"*. A comprehensive framework of constructivism and navigation was presented that consolidated key themes in constructivism and identified implications and hypotheses from these themes for the employment of navigation aids in educational electronic texts. This provided grounding for the experimental research in this thesis. Chapter 3 also described the selection of two sets of hypotheses for further investigation, in order to build on previous research on navigation aids and learning. The first set concerned the effects of navigational freedom (the degree of choice a learner has in deciding which page to visit in an electronic text) on learning. The second set concerned the effects on learning of a novel approach to navigation: allowing the learner to create their own navigation aids.

Two experimental studies were designed to test the hypotheses, and a third experiment extended the research further and was motivated by the findings of the second experiment. These experiments fulfil **objective 3**: "*To empirically test hypotheses that were motivated by the framework of constructivism"*. Experiment 1 was described in chapter 4. This experiment was designed to investigate the effects on learning of the level of navigational freedom offered by four types of navigation aids: paging buttons (lower navigational freedom); embedded links (medium navigational freedom); an A-Z index (higher navigational freedom); and a map (higher navigational freedom). The findings of experiment 1 revealed that navigation aids that offered higher navigational freedom had little effect on learning. Explanations for these findings were considered in terms of cognitive load theory and in terms of navigation behaviour and usability.

Chapter 5 then described experiment 2, designed to investigate the effects on learning of allowing learners to create their own navigation aids. This experiment investigated the effects of *using* versus *creating* three different types of navigation aids: a map, an A-Z index and a contents list. Post-hoc analyses of navigation behaviour and usability problems were also conducted. The findings of experiment 2 indicated that allowing learners to create their own navigation aids had little or negative impact on learning, and that cognitive load appeared to be an important factor in the use of navigation aids in educational electronic texts. As such, in Chapter 6, experiment 3 extended the work in experiment 2. This experiment investigated the effects of allowing learners to adapt existing navigation aids, specifically maps. The findings indicated that allowing learners to adapt maps had benefits for some aspects of learning, as well as for subjective ratings of cognitive load. In addition, a secondary finding was that adapting maps had benefits in terms of usability.

To meet **objective 4**, "*To distil the findings of these empirical investigations into a set of implications to inform designers and researchers of educational electronic texts*", the implications of experiments 1, 2 and 3 were summarised at the end of chapters 4, 5 and 6 respectively. These implications are revisited in this chapter in section 7.3.

The remainder of this chapter discusses the overall outcomes of the research. The scope of the experimental studies is discussed in section 7.2 in order to provide a basis for interpreting the findings and their implications. In section 7.3 the implications of the findings from experiments 1, 2 and 3 are summarised. Then, in section 7.4, these implications and the findings of the experiments are considered in relation to the framework of constructivism and navigation in order to relate the experimental findings and implications back to constructivism. In section 7.5, contributions of the research are discussed and in section 7.6 the limitations of the research are described. Finally, in section 7.7, suggestions for future research on navigation aids and learning are identified and in section 7.8 overall conclusions are drawn.

7.2 Scope of the Experimental Findings

There are seven key factors that define the scope of the experimental findings:

1. In this research, learning was approached from a broad perspective, as the process of constructing knowledge. This meant that in the experiments learning was not just considered from the perspective of performance on post-test outcome measures. Instead, learning was evaluated from the perspectives of cognitive engagement and learners' feelings of ownership for their learning, as well as in terms of the quality of knowledge construction. As highlighted in the implications of experiment 3, the apparent effects of navigation aids on learning may be different depending on how learning is measured. This research did not consider the effects of different navigation aids on simple short-answer factual knowledge, or multiple choice questions about the content of the electronic text, since these were considered to assess learning at a surface level only. However, the findings of the experiments may have been different if such measures had been employed.
2. The electronic text used in all three experiments was on the subject of usability evaluation. There was no set order or manner in which learners should be exposed to the topics in usability evaluation. The text was therefore written in such a way that there was no particular order in which the topics should be read, and could be organised according to the different types of navigation aids in these experiments without altering the text content. Hence, the findings presented in experiments 1-3 may be particularly relevant to texts where the structure and order in which topics should be presented in is not predefined. The effects of the navigation aids used in these experiments may be different when employed in electronic texts where the subject-matter is highly structured, such as in biological classification systems or where events are described in chronological order.
3. The findings of these studies are also relevant to the use of electronic texts in self-contained educational activities, such as those that might be used in a tutorial session. The main experimental task that participants were asked to perform in experiments 1-3 was an example of such an activity. However, the findings presented in this thesis might not be applicable to longer-term educational tasks, for example where learners use electronic texts in a long-term project.
4. Another factor in the scope of the experimental findings is that all the participants in the experiments were new to the information in the electronic text. This is important since it has been found that navigation aids may have different effects on learning with electronic texts when learners have different levels of prior knowledge of the

text content (McDonald and Stevenson, 1997b). As such, the findings of experiments 1-3 are particularly relevant for novice learners.

5. The setting of the experiments also has implications for the scope of the findings. For experiments 1 and 2, the experimental setting involved the participants working individually with the electronic text. Only the participant and the experimenter were present. Consequently, the results of these experiments are particularly applicable to learners working alone with electronic texts. As discussed in chapter 6, the experimental setting was slightly different in experiment 3 and participants used the electronic texts in a computer laboratory. Up to six participants took part in the experiment at any one time. The setting of this experiment can be seen as more realistic and the results are applicable to situations where learners work individually but within a computer laboratory class.
6. The navigation aids used in these experiments were selected on the basis of which ones were most appropriate for testing the experimental hypotheses and focussed particularly on a group of popular aggregate navigation aids (maps, A-Z indices and contents lists) and singular navigation aids (embedded links and paging buttons). Typical examples of each of these types of navigation aids were used in these studies. For example, the contents list showed all page titles in the electronic text and pages were arranged in one possible logical order with indentations to show conceptual groupings. There are other possible ways that a contents list might be organised, for example as a drop down list, or as a top level of pages in the electronic text. As such, the findings about the effects of these navigation aids on learning may be different with different versions of these generic types of navigation aids.
7. Finally, the experiments presented here concerned the effects of navigation aids on individual learners. The results may have differed if the effects of navigation were considered with groups of learners collaborating as they used educational electronic texts.

7.3 Summary of Implications from the Experiments

The implications of the findings from experiments 1-3 are summarised here to provide a basis for the discussions in the next section (section 7.4). Eight key implications have been identified from the experimental findings. These should be understood within the scope of the experiments as discussed in section 7.2.

1. Designers of educational electronic texts should not assume that navigation aids that offer higher navigational freedom will have benefits for cognitive engagement, feelings of ownership for learning, or high quality knowledge construction as compared to navigation aids that offer lower navigational freedom. Navigation aids that offer higher navigational freedom were found to provide no significant benefits for learning as compared to navigation aids that offer lower navigational freedom.
2. Designers should consider using paging buttons as navigation aids in educational electronic texts. Paging buttons were found to have benefits in terms of the development of high quality knowledge construction in experiment 1. It appeared that learners benefited from this lower level of navigational freedom, and arguments were presented that this was due to low cognitive load associated with navigating with paging buttons.
3. Designers should exercise caution when employing embedded links as navigation aids in educational electronic texts. Although embedded links were found to have benefits for some cognitive engagement activities in experiment 2, in experiments 1 and 2 they were found to have detrimental effects in terms of the quality of knowledge construction. This thesis argued that this was due to high extraneous cognitive load and usability problems associated with disorientation.
4. Designers should not assume that allowing learners to create their own navigation aids will have benefits for cognitive engagement, feelings of ownership for learning, or higher quality knowledge construction. Creating navigation aids was found to have little or negative effects on these aspects of learning. In particular, experiment 2 revealed the following implications for creating and using maps, A-Z indices and contents lists:
   a. Designers should be aware that creating a map had little, or negative effects on the learning measures in experiment 2.
   b. Designers should be aware that creating an A-Z index had little effect on the learning measures in experiment 2 compared to using A-Zs and embedded links.
   c. Designers should be aware that creating a contents list had no significant effects on any of the aspects of learning measured in experiment 2 compared to using contents lists and embedded links.

5. Designers should consider using maps and contents lists as navigation aids in educational electronic texts. Using a map was found to have benefits over embedded links in terms of some cognitive engagement activities, ownership for learning and knowledge construction. Using a contents list was found to have benefits over embedded links in terms of some cognitive engagement activities feelings of control for learning and knowledge construction.
6. Designers of educational electronic texts who want to encourage feelings of ownership for learning, and provide usable navigation with lower cognitive load should consider allowing learners to adapt existing maps. In experiment 3, allowing learners to adapt maps was found to have benefits for feelings of control and responsibility for learning. Adapting a map was also found to have benefits in terms of lower cognitive load and good usability, particularly compared to embedded links.
7. Designers should also be aware that they may have to consider trade-offs between benefits for different types of knowledge construction. It was found that adapting maps had benefits for one aspect of knowledge construction (the explanation of usability evaluation in the transfer task) compared to creating or using maps or using embedded links, whereas for another aspect of knowledge construction (details of the evaluation techniques and their advantages/disadvantages in the transfer task) they had negative effects compared to these other navigation aids.
8. Designers and researchers should be aware that navigation aids may have different effects on learning depending on the context in which they are used. For example, some differences were noted between the findings of experiments 1-3 and previous research. In addition, the findings of experiments 2 and 3 also showed some differences for comparisons of using maps, creating maps, and using embedded links. Important issues appear to be the type of system used, the measures of learning and the social context in which the effects of the navigation aids are used.

7.4 Relation to the Framework of Constructivism

The implications of the experimental findings can be used to inform designers of educational electronic texts. In order to consider the findings in terms of the wider scope of constructivism as a whole, they are re-examined in terms of the themes in the framework of constructivism. This section initially revisits the experimental findings for the hypotheses selected from the framework. This is followed by an examination of how the experimental findings relate to the other themes in the framework that were considered relevant to navigation in educational electronic texts and the hypotheses that were identified under these themes. Themes 2 ("Multiple Perspectives Facilitate Learning"), 3 ("Authentic Activity Facilitates Learning) and 8 ("Disequilibrium Facilitates Learning") are not discussed here since they were not considered relevant to navigation aids in electronic texts in chapter 3.

7.4.1 Theme 1: Learner Involvement Facilitates Learning

As discussed in the framework of constructivism in chapter 3, in this thesis learner involvement was proposed to relate to three key issues: learner control, motivation, and feelings of ownership for learning. In this thesis it was also proposed that the three issues are all inter-connected, where learner control is the component that can be manipulated by the environment, and motivation and ownership are resultant feelings or behaviours.

The relationship between learner control and navigation was then considered, and navigational freedom was put forward as one interpretation of learner control over navigation in electronic texts. The following hypothesis was selected from the framework for further investigation: *"Learners who use navigation aids that offer higher navigational freedom will show higher quality learning than learners who use navigation aids with lower navigational freedom"(hypothesis 1 b)i)).* This hypothesis was then broken down into three further hypotheses that predicted that higher navigational freedom would have positive effects on cognitive engagement, ownership for learning, and knowledge construction (H_1, H_2 and H_3). Experiment 1 was designed to test these hypotheses. In this experiment, learners were provided with navigation aids that offered different levels of navigational freedom as summarised in section 7.1 of this chapter. As discussed, the findings suggested that navigation aids that offer higher navigational freedom had little effect on cognitive engagement, ownership and knowledge construction, as compared to navigation aids that offered lower navigational freedom. In fact, paging buttons, which offered lower navigational freedom, were found to have the greatest benefits for the quality of knowledge construction, particularly in comparison to embedded links.

Issues of learner control over navigation were also investigated in experiment 2. In that experiment, another interpretation of learner control was considered: offering the learner the control to articulate their ideas through creating their own navigation aids. By creating their own navigation aids, learners had the control to make choices and decisions over the content, structure and layout of their navigation aid. This was hypothesised to have positive effects on cognitive engagement, ownership and the quality of knowledge construction (H_4, H_5 and H_6). These hypotheses were tested with three different types of navigation aids: a map, an A-Z index and a contents list. However, as discussed in section 7.3, the findings of experiment 2 were not as predicted; it was found that creating navigation aids had little or negative effects on cognitive engagement, ownership and knowledge construction.

When the results of experiments 1 and 2 were considered together it appeared that learner control over navigation, in the form of navigational freedom and creating navigation aids, had little benefit for learning with electronic texts. In chapters 4 and 5, cognitive load was given as one potential explanation for these findings. It seemed that with higher learner control over the navigation, particularly through creating maps and contents lists, there was also an increase in extraneous cognitive load. The suggestion that high control over navigation can have negative effects has also been proposed in previous research. Gupta and Grampadhye (1995) pointed out that although giving learners control over their navigation allows them to select their own paths through an electronic text and "navigate freely in tune with their individual needs and capabilities", it also obliges the learner to make decisions and constantly assess their state of progress. This forces the learner to use high-level intellectual processes whilst navigating, therefore reducing the amount of cognitive resources available for understanding the content of the text. They also argued that control *is the cause* of some navigation problems, such as disorientation, because of higher cognitive load. This highlights that the way that the implications of constructivism are interpreted is important in determining the effects on learning.

Nevertheless, the findings of experiment 3 suggested that there could be a compromise between learner control and cognitive load. Experiment 3 extended the work in experiment 2 and examined the impact of offering control to the learner through allowing them to adapt existing map navigation aids. It was hypothesised that allowing learners to adapt navigation aids would have benefits for ownership, knowledge construction, and cognitive load, as compared to creating or using maps, or using embedded links. The findings revealed that adapting maps indeed led to higher feelings of control and responsibility for learning (component factors of ownership), and lower cognitive load. A secondary finding was that adapting maps led to higher ratings of the usability of the electronic text. This suggested that allowing the learner to adapt maps offered a balance between control and cognitive load for feelings of control and responsibility and usability.

Overall, these discussions of learner control suggest that while learner control over navigation is desirable from the standpoint of constructivist learning, it is important that designers are aware that it may have negative effects and implications for the level of cognitive load experienced by learners.

7.4.2 Theme 5: "Tools and Signs Facilitate Learning" (The Articulation/Externalisation of Knowledge)

Experiment 2 aimed to examine the effects of offering learners the opportunity to articulate or externalise their ideas about the content of an electronic text through allowing them to create their own navigation aids. This relates to the following hypothesis from the framework: "*Learners who create their own navigation aids will show higher quality learning than learners who use existing navigation aids" (hypothesis 5 b)ii)).* This hypothesis was then broken down into three further hypotheses that predicted that creating navigation aids would have positive effects on cognitive engagement, ownership for learning, and knowledge construction (H_4, H_5 and H_6). Experiment 2 was designed to test these hypotheses. As discussed in relation to learner control in the previous section, the effects of using versus creating maps, A-Z indices and contents lists were examined. It was found that creating navigation aids had little or negative effects on learning with electronic texts. As such, it appeared that the opportunity for articulation offered by allowing learners to create their own navigation aids was associated with little or negative effects on learning. As argued in chapter 5, it may be that this articulation incurs a level of cognitive load that actually impedes learning.

Previous research has demonstrated that articulation and the externalisation of ideas through summarisation and self explanation are beneficial to learning (Koshmann and LeBaron, 2002; Davis and Hult, 1997; King, 1992; Aleven and Koedinger, 2002). However, it is possible that the articulation involved in creating a navigation aid is not the same type of activity, in that creating a navigation aid may not have involved summarisation and self explanation. Therefore, creating a navigation aid may not have involved the type of articulation and externalisation of ideas that is conducive to high quality learning. This also highlights that the way that the implications of constructivism are interpreted is also important in determining the effects on learning.

7.4.3 Relation to Other Themes in the Framework Relevant to Navigation Aids

Experiments 1, 2 and 3 were explicitly set up to test particular hypotheses from the framework of constructivism and navigation. However, the findings are also considered here in relation to the other hypotheses identified in the framework. The aim of this is to determine whether the experimental findings can "shed light" on any of these other hypotheses. As mentioned previously, themes 2 ("Multiple Perspectives Facilitate Learning"), 3 ("Authentic Activity Facilitates Learning") and 8 ("Disequilibrium Facilitates Learning") are not dealt with here because in chapter 3 they were not deemed relevant to navigation aids in electronic texts.

7.4.3.1. Relation to Theme 4: "Social Interaction Facilitates Learning"

Theme 4 in the framework of constructivism led to the identification of the following hypothesis: *"Learners who use navigation aids that offer interaction with others during navigation will show higher quality learning than learners who use navigation aids that do not offer interaction with others"(hypothesis 4 b)i)).* However, experiments 1, 2 and 3 only addressed issues where a single learner interacts with a single computer. As such, these issues are not covered by the experiments in this thesis and highlight an area for future research (see section 7.7.2).

7.4.3.2. Relation to Theme 5: "Tools and Signs Facilitate Learning" (New/Alternative Representations of the Text Content)

In addition to the hypothesis about creating navigation aids (hypothesis 5 b) i)), the following hypothesis was also identified from theme 5 in the framework of constructivism and navigation: *"Learners who use navigation aids that offer new/alternative representations of the text content (e.g. overviews of the electronic text content) will show higher quality learning than learners who use navigation aids that do not offer these representations" (hypothesis 5 b)i)).* Although experiments 1, 2 and 3 were not explicitly designed to test this hypothesis, their findings do have some relation to this prediction.

In experiment 1, the A-Z index and map provided overviews of the text content, whereas the paging buttons and embedded links did not. However, the findings of experiment 1 indicated that the A-Z index and the map provided no significant benefits in terms of any of the measures of learning (cognitive engagement, ownership and knowledge construction) as compared to the paging buttons and hypertext conditions, where no overviews were provided. As such, the findings of experiment 1 do not lend support to this hypothesis.

Nevertheless, the findings of experiment 2 tell a slightly different story with regards to this hypothesis. In experiment 2, overviews were provided in the using map, using A-Z and using contents list conditions. In the creating conditions, on the other hand, participants had to create their own overview. It was found that learners who were provided with an overview of the electronic text, when they used a map or used a contents list, showed better performance in tests of their knowledge construction as compared to participants who used embedded links only, where no overview was provided. This suggests that in experiment 2 participants who were given an overview of the electronic text, by means of a map or a contents list, did do better in terms of knowledge construction than participants who used embedded links only. These findings provide some support for the above hypothesis. However, the fact that there were no differences on any of the learning measures in comparisons between using an A-Z index and using embedded links only, again suggests that the findings in relation to this hypothesis are not straightforward. It appears that only the map and contents list overviews were significantly useful compared to embedded links alone, where as an A-Z index overview was not significantly useful compared to embedded links alone. In experiment 3, only the overview provided by the adapting map condition had benefits for any of the learning measures here (in particular for ownership). This again highlights that the findings on the utility of an overview were mixed in this thesis.

7.4.3.3. Relation to Theme 6: "Metacognitive Activities Facilitate Learning"

Two hypotheses concerning the effects of navigation aids on learning with electronic texts were identified under theme 6. The first was: *"Learners who use navigation aids that show them where they have been, and where they might go next, will show higher quality learning than learners who use navigation aids that do not provide that information" (hypothesis 6 b)i)).* The second hypothesis identified under this theme was: "*Learners who use navigation aids that support navigation planning will show higher quality learning than learners who use navigation aids that do not provide this information (hypothesis 6 b)ii))."*

In relation to the first hypothesis, the navigation aids in experiments 1, 2 and 3 did not explicitly support the learners' ability to see where they had been and where they might go next. Hence, this hypothesis cannot be considered in light of the data from these experiments. In relation to the second hypothesis, by providing overviews of the electronic text, the maps, A-Z indices, and contents lists in experiments 1-3 may have aided learners in seeing where they might go next, and thereby encouraged some navigation planning. However, since these navigation aids were not specifically intended to provide this information, the findings of experiments 1, 2 and 3 were not considered sufficient to test these hypotheses.

7.4.3.4. Relation to Theme 7: "Connecting Experiences Facilitates Learning"

Two hypotheses were identified under theme 7 in the framework of constructivism and navigation. The first was: *"Learners who use navigation aids that support access to previously visited information, and allow the manipulation and reorganisation of that information, will show higher quality learning than learners who use navigation aids that do not support this (hypothesis 7 b)i)."* This hypothesis may be related to the investigations of creating vs. using navigation aids in experiment 2 and the creating map condition in experiment 3. For example, in the creating navigation aid conditions (map, contents list, or A-Z index) each time the learner visited a page it was displayed in a left-hand window. These pages could be rearranged to create a map, contents list or A-Z index of the pages in the electronic text. As such, the process of creating a navigation aid with Nestor Navigator did in fact support access to previously visited information that could be manipulated or reorganised by the learner. However, the findings of experiment 2 do not lend support to this hypothesis, since creating navigation aids was found to have little or negative effects on learning as compared to using navigation aids in experiments 2 and 3. But, this assertion should be interpreted with caution since the experiment was not explicitly set up to test this hypothesis and further experiments with navigation aids that specifically support access to previously visited information that can be manipulated should still be conducted.

The second hypothesis identified under the Connecting Experiences theme in the framework of constructivism was: *"Learners who use navigation aids that show connections across new information will show higher quality learning than learners who use navigation aids that do not show this (hypothesis 7 b) ii))"*. Maps may be seen as navigation aids that show connections across experiences. As discussed in chapter 3, concept maps have been proposed to be a useful tool for representing connections across experiences (Boud et al., 1985a) and have been found to be beneficial as navigation aids in educational electronic texts in previous experimental research (McDonald and Stevenson, 1999). In this thesis, the findings of experiment 2 revealed that using a map offered benefits over embedded links alone. Similarly, in experiment 3, although using maps did not lead to significant benefits over embedded links, adapting existing maps did. The act of adapting a map may in fact have showed connections across pages in the electronic text more effectively than simply using a map for navigation. As learners navigated in the adapting map condition in experiment 3, not only were they provided with the same map as in the using map condition, but every time they traversed links that were not already represented on the map, these new links were added to the map. Therefore, the adapting map condition may have reinforced the connections between pages to a higher degree than the using map condition. However, the results of experiment 1 showed that maps had no significant benefits for learning as compared to A-Z indices, embedded links, or paging buttons. Consequently, this again leads to the conclusion that although maps may offer benefits to learning in some circumstances, this thesis has revealed mixed findings.

7.5 Contributions

This thesis research has provided a detailed examination of navigation in educational electronic texts in the form of theoretical and empirical investigations. The main implications of the experiments for designers and researchers of educational electronic texts and the relation of the findings to the framework of constructivism and navigation have been described. This work has helped define some of the problems and complexities involved in deciding which navigation aids are most appropriate in educational electronic texts. The contributions of the thesis research are discussed here.

7.5.1 Key Contributions

This thesis has provided a rich insight into the effects of navigation aids on learning within the wide context of constructivism. Four key contributions were identified from the research. This section discusses these contributions in turn.

7.5.1.1. A Framework of Constructivism and Implications for Navigation Aids

It was apparent from the literature review in chapter 2 that there have been several different accounts of constructivism and previous research has given little consideration to the implications of constructivism for navigation aids in educational electronic texts. The framework of constructivism and navigation presented in this thesis extended previous work by synthesising themes that emerged in constructivist principles and literature into one detailed account of constructivism for use in this research. The implications of the themes in the framework for navigation aids in educational electronic texts were identified and hypotheses about the effects of navigation aids on learning were framed. In this research, the framework provided a broad context for investigations into the effects of navigation aids on learning with electronic texts.

The framework also provides a novel and structured way for designers and researchers of electronic texts to think about the effects of navigation aids on learning, and the areas of the framework that have not been specifically subjected to empirical investigation in this thesis represent directions for future research.

7.5.1.2. Three In-Depth Experimental Studies

As discussed in chapter 2, previous research into the effects of navigation aids on learning has generally focussed on systems that do not reflect recent developments in electronic texts and navigation aids. It was also argued in chapter 2 that there was room for further investigations that focussed on the effects of navigation aids on the whole learning process, rather than simply performance measures. This thesis extended previous research with controlled experimental studies that examined novel navigation technologies and, in line with a constructivist approach, focused on evaluating the effects of navigation aids on several aspects of the learning process. The experiments here considered learning from the perspective of cognitive engagement, the learners' feelings of ownership, and knowledge construction.

7.5.1.3. Substantial Qualitative and Quantitative Analyses of the Experimental Data

A large amount of data was produced by the experimental studies in this thesis. This was subjected to detailed qualitative and quantitative analyses in order to determine the effects of navigation aids on several measures of learning, cognitive load, usability and navigation behaviour (see appendices). This provides information that can be interpreted by designers and researchers of educational electronic texts.

7.5.1.4. Experimental Findings and their Implications for Designers

Although the analysis of the experimental data itself was one major contribution of this thesis, implications of this data were also important since they provided a practical interpretation of the data to inform designers and researchers. The implications distilled the main experimental findings and were summarised at the end of each experiment. The overall implications of the three experiments were also summarised in section 7.3 of this chapter and provide an important overview of the findings of the studies. The implications highlight the complex effects of navigation aids on learning with electronic texts.

7.5.2 Secondary Contributions

In addition to the three main contributions of the thesis, the nature of the experimental studies resulted in two further secondary contributions: novel approaches to assessing learning in experiments; and investigations of navigation behaviour, usability and cognitive load.

7.5.2.1. Novel Approaches to Assessing Learning in Experiments

Determining appropriate measures of learning in experimental studies is difficult. In this research, learning was evaluated from a constructivist perspective. However, as Jonassen (1991) pointed out, the way that learning is evaluated is one of the most difficult issues for constructivism, and he laid out some criteria for evaluating learning in constructivist learning environments (Jonassen, 1991; Jonassen, 1992) (see chapter 3 for more details). Accordingly, learning was considered in terms of a number of different measures, and novel approaches to assessing learning were developed for use in the experiments. To summarise, these were:

- ⇨ A coding scheme for assessing cognitive engagement from learners' verbalisations as they interacted with an educational electronic text.
- ⇨ An ownership questionnaire for measuring feelings of control, responsibility and value (the factors of ownership) when using educational electronic texts.
- ⇨ Two tasks to assess knowledge construction and accompanying marking schemes: a transfer task and a concept-mapping task.

These measures could therefore be adapted for use in future investigations that intend to take a constructivist approach to assessing learning.

7.5.2.2. Investigating Navigation Behaviour, Usability, and Cognitive Load

Previous research has shown a link between navigation behaviour and learning with electronic texts (Neiderhauser et al., 2000; McDonald and Stevenson, 1997a; McDonald and Stevenson, 1999). In this thesis, post-hoc analyses of navigation behaviour were employed to examine potential explanations for findings on the learning measures. Across experiments 1 and 2, the number of operations and the number of different pages visited (whether or not participants visited all the pages in the electronic text) proved useful in providing potential explanations for the findings on the learning measures. In experiment 2, usage analysis for the aggregate navigation aid, back button, and link usage also proved useful in revealing possible reasons for the findings on the learning measures. However, as will be discussed in section 7.7, further investigation is needed to determine the true nature of the relationship between navigation behaviour and learning, since here it was only a secondary measure and was not the main focus of the experiments.

Previous research has looked at navigation performance as a measure of usability of electronic texts on the web (e.g. Smith, 1996). It has also examined think-aloud protocols for evidence of usability problems in a web environment. For example, van den Haak et al. (2003) examined usability problems identified from think-aloud protocols given by users of an online library catalogue. However, there appears to be little formal research literature reporting usability problems identified from think-aloud protocols whilst learners use educational electronic texts. In this research, think-aloud protocols from a total of seventy-one learners who used educational electronic texts with different navigation aids were examined in detail for usability problems. Criteria for identifying usability problems in the protocols were developed and the types of usability problems experienced by learners as they used educational electronic texts were classified. In this thesis, the data was used to examine possible explanations for findings on the learning measures in these experiments. This data also offers information for designers of educational electronic texts and provides a general insight into the usability of these texts. However, further research is needed since this data was only collected as explanatory measures in this thesis.

Previous research has also examined usability of electronic texts on the web in terms of users' attitudes (Teo et al., 2003). Similarly, in experiment 3 of this thesis, the learners' attitude towards the usability of the educational electronic text was assessed. This also provided information about the usability of the educational electronic texts in this experiment. Again, however, this measure of usability was secondary to the aims of the experiment, so further research is needed to determine whether the effects of navigation aids on subjective ratings of usability are the same in other situations.

Finally, experiment 3 also examined the effects of navigation aids on learners' subjective feelings of cognitive load. As discussed previously in this thesis (see chapters 2, 4, 5 and 6), although much previous research has *discussed* the relationship between navigation and cognitive load (Niederhauser et al. 2000; Gupta and Grampadhye, 1995; Boechler, 2001; Brunstein et al., 2004; McDonald and Stevenson, 1999), little research has actually *measured* the effects of navigation on cognitive load. In contrast, the approach taken here was to measure subjective ratings of cognitive load through statements on a questionnaire that related to Sweller's (1988) original definition of cognitive load as the burden that a particular task imposes on the cognitive system. The findings of experiment 3 confirmed the claims of previous literature that the use of embedded links can be associated with a high cognitive load (Conklin, 1987; Niederhauser et al., 2000), particularly in comparison to adapting maps.

7.6 Limitations of the Research

This thesis has contributed useful research on the relationship between navigation and learning. In section 7.2, the scope of the experiments was discussed and the areas where the findings are particularly relevant were identified. This section considers the limitations of the research and areas where the research may be less applicable.

7.6.1 Experimental Measures

Although the measures used in the experimental studies in this thesis were carefully selected there are some limitations that should be noted.

7.6.1.1. Learning Measures

- *Cognitive Engagement.* Cognitive engagement was measured through participants' think-aloud protocols in experiments 1 and 2. As such, the measure was confined to the cognitive engagement activities about which the participants were able to verbalise. As pointed out by Ericsson and Simon (1984), the requirement to think aloud can have some affect on the way participants handle tasks, the time it takes them to complete tasks, and their eventual success in task completion. For some tasks, verbalisation is beneficial, whereas for others it may have detrimental effects on performance (Ericsson and Simon, 1984). However, since all participants had to verbalise, any effects of verbalising on the participants' ability to choose a usability evaluation technique as they used the electronic text would have been present in all conditions.

  It is also noted that some participants may have been better at giving think-aloud protocols than others. Nevertheless, in these experiments, since there were a number of participants in each condition, it was expected that any differences in the participants' ability to think-aloud would have balanced across conditions. In future research, differences in participants' ability to think-aloud could be controlled by assessing their ability to think aloud in a separate task similar to the experimental task and including this as a co-variate in the data analysis.

- *Ownership for Learning.* This thesis has reported analyses of the ownership questionnaire showing that it is a reliable and valid measure. However, further insight into ownership for learning could be gauged by more in-depth assessments of ownership, for example through interviews with learners. This would allow learners to justify and explain their feelings of ownership without being confined to the set ratings that participants had to choose from on the ownership questionnaire. Nevertheless, the ownership questionnaire proved to be a useful tool for assessing feelings of ownership within these experiments.
- *Knowledge Construction*
    - *Written Transfer Task.* The written transfer tasks in experiments 1-3 were useful for examining the participants' ability to apply the knowledge they gained whilst using the electronic text. Analysis also showed that the marking schemes used to evaluate the written transfer tasks were reliable and valid. However, since the tasks required participants to select what they thought were the most relevant aspects of their knowledge for the task, it may not have been a good reflection of the breadth of participants' knowledge. But, this task was only taken to assess one aspect of knowledge construction and can be seen to be useful within the confines of what the task aimed to measure.
    - *Concept-Mapping Task.* The concept-mapping task aimed to measure participants' conceptual knowledge of the electronic text, and analysis of the reliability and validity showed the marking to be reliable and valid. Similar experimental research on learning with electronic texts has used concept maps to assess learning (e.g. McDonald and Stevenson, 1997b; Stanton et al. 1992; Shapiro, 1998). However, the question arises as to whether this measure was confounded by the information embedded in the navigation aids in the different conditions of experiments 1, 2, and 3. For example, when comparing findings for an A-Z index to paging buttons (experiment 1) and embedded links (experiments 1 and 2), it can be argued that an A-Z index presented additional information that was not presented by the embedded links or paging buttons. The A-Z index displayed the page titles in the electronic text, and therefore gave participants a double exposure to this information. The same was true when comparing the contents list to embedded links (experiment 2), since the contents list also gave a double exposure to the page titles, and indentations on the list gave information

about the conceptual structure of the text. Additional issues arose when comparing findings for using maps to paging buttons (experiment 1), embedded links (experiments 1, 2, and 3), the creating map condition (experiment 2), and to the adapting map condition (experiment 3). In these cases, the using map condition provided participants with one "ideal" structure for the information in the electronic text. This may have influenced participants' performance on the concept-mapping task and the task may have measured something other than participants' conceptual knowledge. For example, this might have been participants' ability to reproduce page titles from the A-Z or contents list, or the participants' ability to reproduce the map presented in the using map condition. However, there are several counter arguments to this.

Firstly, the way that the concept-mapping tasks were marked did not only assess knowledge at the level of page titles. The qualitative marking scheme assessed participants' ability to give details of the underlying concepts in the electronic text, rather than just representations of the page titles. Good link labelling was also awarded marks since it made the conceptual nature of the relationships more explicit. High qualitative marks, therefore, could not be achieved by simple lists of the page titles in the electronic text, or even by a complete reproduction of the map given for navigation. High qualitative marks required information about the underlying concepts in the content of the electronic text. A perfect reproduction of the map navigation aid could gain no more than 50% for the qualitative marks. Furthermore, if the highest marks were gained simply by reproducing the map, then participants in the map condition in experiment 1 would have been expected to get the highest marks. In contrast, it was the participants in the paging buttons condition who gained the highest marks on the concept-mapping task in experiment 1.

Secondly, in the instructions for the concept-mapping task for all three experiments, participants were at no point asked to simply reproduce the page titles in the electronic text.

Finally, even if participants did reproduce information from the A-Z index, contents list, or maps, in their hand-drawn concept maps, the result is still desirable. Whether they gained conceptual knowledge by reference to a navigation aid, or whether they constructed it themselves from the text content, it is the fact that they have this knowledge that is important. Because of the constructive nature of memory (e.g. Bartlett, 1932), even to be able to recall and reproduce a map or page titles should require some level of interpretation of what the map or page titles represent.

As such, some caution should be exercised when interpreting the findings for the concept map measures, but the arguments for the validity of the measure should be noted. Moreover, because the concept-maps were not the only measure of learning on which the conclusions of the thesis are based, any issues with the measure do not significantly affect the implications of this thesis research.

7.6.1.2. Navigation Measures (Experiments 1 and 2)

The navigation measures were selected on the basis that they were most appropriate for the open ended nature of the experimental tasks given to participants in experiments 1 and 2. However, some limitations of these measures should be considered.

- *Number of Operations.* As discussed in chapters 2 and 4, this has been employed as a standard measure in much previous research on navigation in electronic texts (McDonald and Stevenson, 1997b; McDonald and Stevenson, 1998; Stanton et al., 1992; Wenger and Payne, 1994; Nilson and Mayer, 2002; Danielson, 2002; Gupta and Gramopadhye, 1995). However, since the tasks given to participants as they used the electronic texts in experiments 1, 2, and 3 were open-ended, and they were not required to locate specific information, it was hard to interpret whether a higher number of operations was better than a lower number of operations, or vice-versa. A higher number of operations may indicate intensive exploration, which may be valuable in terms of learning. On the other hand, a higher number of operations may also be indicative of inefficient navigation, or even perhaps confusion. One solution may have been to examine the number of page revisits, but this would have had the same problem. Taking a constructivist viewpoint, a high number of revisits may have been considered a good result because it indicated that the participants were revisiting information from a number of different perspectives. On the other hand, a high number of page visits may have indicated that a participant was confused and had to keep re-checking information in the text. In experiments 1 and 2, the aim of this measure was simply to gain additional information to offer potential explanations for findings on the learning measures. As such, the number of operations was not considered as a measure of the quality of the navigation aid in its own right.

- *Number of Different Pages Visited.* The aim of this navigation measure was to gain an overview of the extent to which participants in experiments 1 and 2 covered the information in the electronic text. However, a page visit was recorded even when the page was displayed only very briefly. Therefore, the fact that the page had been visited was not necessarily indicative of whether a participant had actually taken the information in. Previous research has attempted to make adjustments for this type of problem by only counting page visits as those pages that were displayed for a sufficient amount of time for the pages to be read. For example, Wenger and Payne (1994) determined a page to have been read if it remained open for ten seconds. According to their measures, at an average reading speed of 200 words a minute, ten seconds would have allowed their participants to read approximately thirty-three words, or about twenty-five percent of the text on an average page in their electronic text. However, such an adjustment was not considered appropriate in this research since it did not account for page scanning. Important information can be extracted from stimuli within milliseconds (Potter, 1993), therefore, it is very difficult to set a cut off point for when information has been extracted from a page.
- *Back Button, Link and Aggregate Navigation Aid Usage.* In experiment 2, this measure aimed to examine the percentage of the total number of operations which involved using the back button, embedded links and aggregate navigation aids. Although this was useful in terms of the actual navigation operations, it did not give information about the extent to which participants were using the semantic information provided in the navigation aids. For example, the aggregate navigation aids in the using map, using A-Z, using contents list, creating map, creating A-Z, and creating contents list conditions gave information about the structure of the electronic text. In other words, it could not be determined whether participants were referring to the aggregate navigation aid to guide their navigational decisions and were only interacting with the links to perform the navigational operations, or whether they were not using the aggregate navigation aids at all. In order to obtain this information in future, eye-tracking devices could be used to determine what part of the screen the participants were focussing their gaze on.
- *Navigation Map Measures.* These were employed in experiment 3 to explore potential explanations for differences on the learning measures. To this end there were two further aims: firstly, to see how the maps which participants created and adapted differed from those that were provided in the using map condition; and secondly, to determine the extent to which participants in the adapting map

condition actually adapted their maps. The measures addressed the number of nodes, links and conceptual links in the final maps at the end of the experiment and how these differed from the original maps provided at the beginning of the study. Since they only looked at the final maps, these measures did not account for any changes that were made whilst participants used the electronic texts. These measures also only accounted for the content of the maps in terms of the number of nodes, links, and conceptual links in the map, rather than the layout of the map. As such, important information about how the maps were adapted may have been missed. This could be recorded in future research by screen capture methods.

7.6.1.3. Usability Measures

- *Usability Problems.* Usability problems were identified from participants' think-aloud protocols in experiments 1 and 2 as a secondary measure to examine potential explanations for the findings on the learning measures. The aim was to get information about the number and types of usability problems experienced by participants. However, since only the participants' think-aloud protocols were analysed for usability problems, and no observational data was analysed, some usability problems may not have been accounted for in the figures given in these experiments. Previous research by van den Haak et al. (2003) examined the number of usability problems experienced by participants who were asked to think-aloud as they used an online library catalogue. Of the average total number of usability problems per participant, fifty-two percent were identified from their think-aloud protocols. The other forty-eight percent were identified on the basis of observations made by the researchers as the participants used the online catalogue. This suggests that a considerable proportion of usability problems may not be discovered during experiments simply based on think-aloud protocols. However, although this may be a problem in terms of identifying the full set of usability problems experienced by participants in experiments 1 and 2, because it was the same for all experimental conditions it is not a problem when comparing across conditions. In addition, it has already been argued that the participants may have differed in their individual ability to think aloud. Nevertheless, since there were a number of participants in each condition it was assumed that this would have balanced out across conditions. As such, the conclusions about differences between conditions drawn on the basis of the usability problems in this experiment were not affected.
- *Usability Questionnaire.* The usability questionnaire in experiment 3 was used to assess the usability of the navigation aids in that experiment. It was inappropriate for

the participants to think-aloud during the experiment because up to six participants were being tested in any one session. Therefore, the questionnaire was used instead of assessing usability problems through think-aloud protocols. However, because participants were simply asked to rate their attitudes towards the usability of the electronic texts, specific usability problems were not identified and this information was not available for this experiment.

7.6.1.4. Cognitive Load Measure (Experiment 3)

In experiment 3, participants were asked to rate their subjective feelings of cognitive load on a questionnaire. However, it could be argued that this only assessed one aspect of cognitive load – the participants' subjective perception of cognitive load. As discussed in chapter 2, other more objective measures include dual task performance, learning performance, psychophysical measures, such as heart rate variability, and event-related brain potentials (Paas et al. 1994; Dennis et al. 1998; Murai et al., 2004). Nevertheless, the subjective ratings of cognitive load used in experiment 3 were taken in conjunction with the learning measures and these were considered appropriate in this research because they would not interfere with the way that participants used the electronic text. Hence, this provided a sufficient insight into the cognitive load experienced by participants within the confines of this research.

7.6.2 Other Limitations of the Experiments

7.6.2.1. Number of Participants

A total of 103 participants took part in experiments 1-3: twenty nine in experiment 1, forty-two in experiment 2, and thirty-two in experiment 3. However, this represented no more than eight participants in any experimental condition, in any of the three experiments. Although significant findings were discovered, the power of the conclusions that could be drawn from the data would have been increased with a greater number of participants. Nevertheless, given the time and resources available to this research, this number of participants was considered acceptable.

7.6.2.2. Experimental Settings

For experiments 1 and 2, the data was collected in a controlled experimental setting where participants were tested individually. Although this had higher internal validity within the experiments, it also entailed a compromise in ecological validity since the experimental settings may not have been representative of real world situations in which learners use electronic texts. In experiment 3, an attempt was made to extend the ecological validity of the research by running the experimental sessions in a computer laboratory with up to six participants at any one time. However, since the participants were not able to communicate with each other during the experimental sessions, the ecological validity of this setting may be reduced. It is anticipated that the real environments where educational electronic texts are used may involve distractions and communication with others. This was not captured by the experimental settings.

7.7 Future Research

The framework of constructivism and navigation provided a broad context for this research on navigation in educational electronic texts that takes account of a constructivist perspective. Empirical investigations have been conducted to test a set of hypotheses that were motivated by the framework. There are several possible directions for future research to extend the work presented in this thesis, and four main areas have been identified.

7.7.1 Extending the Experiments

Chapters 4, 5 and 6 reported on experiments designed to test hypotheses about the effects of navigational freedom, creating navigation aids, and adapting navigation aids on learning with electronic texts. There are six key ways that the experimental findings could be extended.

1. *Extend the experiments with greater numbers of participants.* This would give greater power to conclusions drawn from the experiments.
2. *Conduct further experiments that place more emphasis on navigation behaviour, cognitive load and usability issues.* Previous research has covered navigation behaviour and to some extent cognitive load, but usability issues in particular need further attention. It is important that future research into learning with electronic texts addresses usability measures in conjunction with learning measures so that the relationship between them can be identified.
3. *Conduct further experiments with electronic texts on different topic areas.* In these experiments, the electronic texts were on usability evaluation. It has been argued in this thesis that this subject-matter has little predefined structure, in that there is no set order in which the topics should be presented to learners. In addition, as suggested by Kukulska-Hulme and Shield (2004), different topic areas and disciplines may have their own specific usability issues in e-Learning. To extend

this work further, future research could consider the effects of navigation aids in electronic texts with different text topics and with texts where the structure is more predefined, for example topics in history where chronological organisation may be appropriate for presenting subject-matter.

4. *Conduct further experiments with different types of experimental tasks.* As discussed in section 7.2, the findings of the experiments presented here were particularly relevant to short-term educational tasks, such as tutorial sessions. This work can be extended by testing the experimental hypotheses in situations where the learners are given long-term projects, so that the effects on learning can be examined over time. Previous research has shown that this is an important factor in learning with electronic texts (McDonald and Stevenson, 1999).
5. *Conduct further experiments with learners who are familiar with the electronic text content.* In this thesis, the experiments were conducted with learners who were novice with respect to the text content and their level of prior knowledge was controlled. To extend this further, future research could be conducted with advanced learners who, for example, are revising the text content, so already have a basic familiarity with the text topic.
6. *Conduct further experiments in real classroom environments.* Experiments 1 and 2 in this thesis were conducted in controlled environments where the learners worked with the electronic texts individually. In experiment 3, although the experiments took place in a computer lab, the learners still worked alone. This research could be extended by examining the effects of the different types of navigation aids in real classroom environments where learners often collaborate and other environmental issues are important, such as the actions of the instructor. This would give the research more ecological validity.

7.7.2 Further Exploration of Hypotheses from the Framework

The experiments reported in this thesis examined a sub-set of hypotheses that were formulated based on the framework of constructivism in chapter 3. These related to theme 1, "Learner Involvement Facilitates Learning", and theme 5, "Tools and Signs Facilitate Learning", in the framework. Although some of the remaining hypotheses have been considered in light of the findings from experiments 1-3 (see section 7.4), hypotheses from themes 4, 5, 6 and 7 still remain to be fully investigated.

7.7.3 Extending the Framework: Other Interaction Issues and Educational Technologies

As discussed in chapter 1, in terms of HCI, the scope of this thesis concerns issues related to navigation aids in educational electronic texts. Accordingly, the framework of constructivism examined the implications of constructivism for navigation in educational electronic texts. To extend this work further, the framework could be used to consider implications of constructivism for other interaction issues and other educational technologies. For example, the framework could be examined in terms of implications for the use of multimedia in the educational content of an e-Learning environment. Alternatively, it could be used to examine the implications of constructivism for communication issues and discussion boards. Consequently, it is apparent that the framework can be used as a basis for a number of future research directions within e-Learning.

7.7.4 Modelling the Effects of the Navigation Aids, Learners, the Electronic Text Content and the Educational Context

The findings from experiments 1-3 have highlighted the fact that the effects of navigation aids on learning are complex. This is emphasised further when the findings are compared with those from previous research on navigation aids and learning. As discussed in sections 7.2 in this chapter, it is apparent that a number of issues were important to the scope of the experiments in this thesis and the following factors were identified as important to determining the effects of navigation aids on learning:

- ⇨ the learners (novice or advanced)
- ⇨ the text content (the natural structure of the text and the text topic)
- ⇨ the learning tasks (short or long-term learning)
- ⇨ the learning context (social and environmental factors)
- ⇨ the learning measures (e.g. cognitive engagement, ownership, knowledge construction)

To inform future research on navigation and learning it would be useful to have a model of the effects of navigation on learning that takes account of each of these factors. This would allow designers and researchers of educational electronic texts to consider any implications or recommendations in terms of these factors for their own educational electronic text systems.

7.8 Conclusions

This thesis has provided a rich insight into the effects of navigation aids on learning with educational electronic texts through detailed theoretical and empirical investigations. The framework of constructivism and navigation offered a broad context for hypotheses about the effects of navigation aids on learning and the experiments designed to test these hypotheses gave in-depth information about these effects. The findings of the experiments highlighted that navigation aids do have a significant impact on some aspects of learning, but that these effects are complex. Since the experimental findings were not always as predicted from the framework of constructivism and navigation, they indicated that the implications of constructivism for navigation aids in educational electronic texts are not straightforward. Comparisons of the experimental findings to those of previous research suggested that several factors, such as the learners, the context of use, the text content, and measures of learning, are central to determining the effects of navigation aids on learning. Thus, designers and researchers should carefully consider these factors, amongst others, when choosing which navigation aid to employ in educational electronic texts.

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