A Visualisation Design for Sharing Knowledge

A virtual environment for collaborative learning support

Luís Manuel Borges Gouveia

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Abstract

This thesis proposes a general structure for knowledge sharing to represent knowledge that allows a group of users to share concept meanings and their relations and to organise information about a specific knowledge theme or context.

Recently, many developments were introduced for presenting information concerning the use of visualisation techniques, including 3D interactive visualisations and virtual environments. The way a group shares information about the meanings of concepts used, defined here as structure for knowledge sharing, is considered an important issue for knowledge sharing and knowledge construction. However, visualisation potential for representing and exploring knowledge has not yet been totally explored.

The study of existing practices in collaborative learning and education environments serves as an initial starting point to get insight into ways of using abstract information and how it can be of value for and between students. Research areas such as CSCL, CSCW, visualisation, and graphical knowledge representations were investigated in order to inform the research. This study has provided the main motivation for the research on how to provide knowledge sharing support for collaborative learning use.

The work also presents the development and evaluation of a partial prototype to test the above ideas. Its aim is to assess how users can collaborate and take advantage of using a common structure for knowledge sharing and a visualisation design for collaborative learning support.

An empirical study conducted suggests that users were able to specify structures for knowledge sharing, use the 3D interactive visualisation to explore the structure and to contribute to the enhancement of the common structure. It also shows that using a particular structure for knowledge sharing provides learning value as a tool for collaborative learning in a higher education context.

The novel aspect in the thesis is the proposal of the use of a structure for knowledge sharing to render a 3D interactive visualisation and allows combining data source information with the use of integrated information. Together these facilities provide an environment for collaborative learning support. The thesis concludes by discussing how to improve current work, new directions for further work and produces a number of recommendations.

To Paula,
and our little Luís

My happy and beloved centre of the world

Where is the life we lost in living?
Where is the wisdom we lost in knowledge?
Where is the knowledge we lost in information?

T.S.Eliot: The Rock (1934)

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1 Introduction

Currently, there is some pressure to improve learning environments and use Information and Communication Technologies – ICT – in innovative educational contexts [Goodyear, 1999]. The ready availability of networks and computers allows for the development of computer-networked systems that support learning activities in classrooms or distributed situations.

However, current systems for collaborative learning [Britain and Liber, 1999] do not support the same knowledge sharing environment that face-to-face situations enjoy. In particular, there are difficulties is representing context and abstracting information about the knowledge theme being discussed. This is a problem that needs to be addressed in order to facilitate support for Computer Supported Collaborative Learning – CSCL [Bannon, 1989]. In particular, knowledge sharing becomes an even greater problem in situations where more traditional teaching, based on the presence of the teacher, is expanded to allow for both local and distance education settings [Wan and Johnson, 1994].

This thesis addresses the problem of how to share knowledge between a group of people engaged in learning activities. In existing systems that support collaborative learning there is some evidence that difficulties occur when we try to:

- support the sharing of knowledge between users;
- support the learning process across distributed groups within a given educational setting;
- provide distributed access to knowledge from different types of machines.

Some authors argue that efforts to improve learning and education must emphasise not only content but also context [Figueiredo, 2000]. In fact, already [Lewin and Grabbe, 1945] defend both, that learners play an active role in discovering knowledge for themselves and the strong influence that the social environment of the learner in promoting changes. Also [Vygotsky, 1978] defends that knowledge results, not from a transmission process, but from the internalisation of social interactions.

New technologies that use 3D visualisation facilities and interactivity within virtual worlds seem to assist in minimising the difficulties by allowing abstract information, in the form of structured knowledge for representing contexts and meanings, to be visually mapped and explored using direct manipulation techniques. Such a representation can complement existing tools to allow context sharing of a given knowledge theme – a view of organising information about a particular knowledge theme.

Collaborative learning is defined as groups working together for a common purpose [Resta, 1995]. To collaborate effectively in group work, each individual's purpose must share a common grounding of concepts and be able to specify them in a form that allows individual reflection within the group. Each user in the group must possess a common mental map representation for reference, to understand the meanings and relations underlying a particular situation, topic, or subject knowledge referred as view. The common use of a visual representation of such a mental map allows for collaborative construction and enhancement, providing the opportunity to augment both individual and collaborative learning. An example of a similar system is CSILE (computer-supported intentional learning environments), which is a collective networked database of students' thoughts in text and graphic form. Data is labelled and organised in such a way that it can be accessed allowing a student to analyse a given view and to access related information in another domain [Scardamalia and Bereiter, 1994]

Information to support the meanings and relations of a mental map can be seen as a common information set of which each user must be aware. As this information comprises abstract concepts and their relations, we propose the need to develop a structure for supporting knowledge sharing for the view to be shared. Few systems explicitly support such abstract information or consider it an important issue for supporting collaborative learning [Beck-Wilson et al., 1999].

This thesis examines how a common structure for knowledge sharing can be used in distributed environments for collaborative learning in a higher education context by providing a 3D interactive visualisation. This work proposes the development of a visualisation design to convey information of the common structure for knowledge sharing to be created and enhanced in an educational context. The claim of this thesis is that the use of both the visualisation design and the structure for knowledge sharing can support collaborative learning.

1.1 The context for the work

The *Visualisation DEsign for Sharing Knowledge* (ViDESK) model proposes the following ideas to support both user and collaborative learning:

- a structure for representing the knowledge theme being shared;
- a visualisation design to convey information about the structure being shared;
- an environment to allow the use of the structure and visualisation design to discuss and collaboratively enhance the knowledge being shared.

This thesis suggests that a system that offers a *Shared visualisation and virtual environment can support collaborative learning* using a structure for knowledge sharing and a visualisation design to convey structure information to complement existing tools that already support student communication such as electronic mail, whiteboards, CSCL and CSCW systems.

The work attempts to propose a visualisation design addressing the problems of:

- *cognitive overhead*: which allows an abstract high level for information representation [Norman, 1991] and thus providing the means to integrate data using Information Visualisation techniques [Card et al. 1999];
- *information overload*: which allows each individual user to take advantage of a structure for knowledge sharing and thus providing a context for reasoning about a particular knowledge theme [Huhns and Singh, 1997].

Additionally, the work is also extended to propose:

- *support for data source integration*: which takes advantage of a visualisation to merge information about a data source with the common structure for knowledge sharing and a textual search engine for Information Retrieval [Baeza-Yates and Ribeiro-Neto, 1999].

ViDESK addresses these problems by using a 3D interactive visualisation based on a structure for knowledge sharing that describes the requisite information. The structure is used to organise abstract information that must be shared for collaborative learning. The proposed solution uses visualisation as a means of creating a projected representation for the structure being shared among different users.

The central claim in this thesis is that with such a visualisation design it is possible to help each individual in a collaborative learning situation by sharing and proposing meanings using an abstract high level for information representation. The visualisation also supports the integration between the constructed structure and a data source. The visualisation can work as complementary to existing systems for collaborative learning by providing itself as an interface.

Overall, the thesis proposes a general structure for knowledge sharing to represent knowledge that allows a group of users to share concepts and negotiate their meanings. It is a simple structure that presents a model to support knowledge, and convey information about the knowledge to be shared among users. The structure aims to support knowledge construction in a collaborative learning environment. To ease user interaction with the structure, a computer based 3D interactive visualisation design is proposed to allow a higher abstraction representation addressing cognitive overhead and information overload.

This work extends previous research on Information and Communication Technologies in education, in particular, using Internet facilities for supporting virtual environments for higher education [Gouveia, 1999a].

1.2 Approach of the work

The study of existing practices in collaborative learning and education environments serves as an initial starting point to get insight into ways of using abstract information and how it can be of value for and between students. The study of literature about face-to-face collaborative learning situations and knowledge construction provide important insights to inform about the characteristics that a virtual world system must have, to support similar functionality.

The potential for Information and Communication Technologies and the impact that these can have in current education settings have been studied. In particular, a brief study of pedagogical issues and theories concerning learning and collaborative learning has been conducted to inform design requirements.

Current CSCL and CSCW systems are discussed in order to address how they provide extended support for collaborative learning. The Collaborative Virtual Environments

(CVEs) are among those systems. A CVE aims to provide support for co-operation by placing users within a shared virtual space that affords particular forms of co-operation [Benford et al., 1997].

A group of empirical studies and experiences conducted to support information and communication use in collaborative learning and knowledge construction are presented and provide evidence which suggests the need for knowledge construction support in learning.

Based on the existing empirical data and from technical solutions developed on existent systems, a number of design solutions were considered. One of those is the use of a structure as the main support for sharing knowledge about a particular theme view – context. Huhns and Singh propose that users can contribute to enhance an existent domain knowledge model [Huhns and Singh, 1997]. Additionally, Huhns and Stephend defend the idea of using a set of symbols to represent a knowledge domain to be used by each individual [Huhns and Stephens, 1999].

The use of a set of symbols in the visualisation design provides a visual mental map representation that can help to keep cognitive overhead and information overload problems minimal. [Tufte, 1990].

As one of the main characteristics of the structure that must be represented is its relationship network, the visualisation design must provide some clues to organise and orient users. The exploration of a three-dimensional space for human interaction seems a natural option to do this: Cyberspace has claimed to provide a three-dimensional field of action and interaction with recorded and live data, with machines, sensors, and with other people [Benedikt, 1991]. According to Wexelblat, a well-structured view can make things obvious to the viewer and empower interaction. The view structure can convey an underlying mental model and can indicate possibilities for interaction in what Wexelblat proposes as semantic spaces [Wexelblat, 1991].

The strategy followed for the visualisation design is to take advantage of collaboration between users to enhance domain knowledge that can be visualised and manipulated by each user for their own information needs and to allow different data sources to be integrated with the structure for knowledge sharing. This will lead to the combination of data source information and knowledge in a way that there is an independent layer between the knowledge being shared and a given data source. Thus providing the user with additional support in analysing both the data source and help in information retrieval activities.

This high level approach allows for a different kind of integration with existing data sources. It allows, in opposite to alternative low level – data – approaches no need to alter existing data sources and apply precise rules for previous identification – classification – of relevant information. However, the data source must provide an interface to search for text keywords, considering the actual ViDESK implementation.

In order to test both the use of the structure for knowledge sharing and the visualisation design, a prototype has been developed to allow a group of students to use the visualisation design for sharing knowledge. The knowledge describes a theme view and is used to support information retrieval from the World Wide Web (Web or WWW) search engine [Baeza-Yates and Ribeiro-Neto, 1999]. The prototype intends to test both the functionality and effectiveness of the use of the structure for knowledge sharing and a visualisation design to support user learning. The learning results from a group of activities such as collaboratively sharing, discussing and enhancing a structure for knowledge sharing.

1.3 Objectives of the work

Considering the 3D interactive visualisation proposed for representing knowledge awareness, the following advantages can be enumerated leading to three work objectives:

- *support collaborative learning* which provids a visualisation design to convey the structure information (giving a visual form to gain knowledge and convey information about it). Once a user learns how to take advantage of the visualisation design he can engage himself in the share, discussion and exploration of the knowledge theme being shared providing a collaborative learning environment.
- *minimise cognitive overhead*: which explores the visualisation design and takes advantage of the navigation facilities offered, the user can explore information about the structure for knowledge sharing as a space allowing a more simple and user friendly alternative for structure presentation in textual form.

- *minimise information overload: the visualisation* deals better with the information overload problem by using a reduced set of symbols to generate the visualisation design. This provides a visual representation for the structure network relationships. The interaction with the visualisation allows information filtering to highlight particular network relationships, providing base functionality to explore the structure for knowledge sharing as a virtual environment taking advantage of the visualisation facility using a three dimensional representation.

A number of additional observations can be made on the basis of experimental trials of the developed system. In particular, four additional experimental conclusions were obtained.

- *ease user interaction*: provides a common interface independent of different knowledge themes: the visualisation design uses the structure for knowledge sharing to generate the symbols used and their position, size and relations. The reduced set of symbols remains the same which allows visualisation independence from the knowledge theme of the structure.

In addition, within the context of the potential for data source information integration, the following advantages can be considered:

- *the provision of a high abstraction level to describe a given knowledge context:* allowing a high description level for use in collaborative learning to discuss models, concepts relationships and confront perspectives about a given knowledge theme. Later, a collaboratively constructed structure can be used to assist information retrieval.
- *support for data source analysis*: based on a given structure for knowledge sharing by comparing the structure with data source information it can be used both as feedback to enhance the structure, and for assisting data source information retrieval.
- *a context meta-description with which to analyse and compare different data sources*: based on a given structure, this allows the user support to start, generate and analyse data source information retrieval results in a given knowledge theme context.

Both use of the structure for knowledge sharing and the 3D visualisation needs to be tested to assess its real possibilities for collaborative learning. Although the traditional computer mouse, keyboard and monitor interfaces may not be the best way to take advantage of the interaction provided by the visualisation design, it still shows the potential of interacting with knowledge.

An important issue is the evaluation of the model derived from the research undertaken. The preliminary evaluation results have indicated the need for more evaluation and further research in order to take advantage and to fully implement the ideas presented in this thesis, although they have confirmed the research goals as valid.

1.4 Novel characteristics of the work

The work defends the need to consider information about tacit knowledge as one of the requirements that must be presented in using Computer Support Collaborative Learning. Other authors defend a similar approach [Lewis, 1999; Mercer, 1995]. One of the main contributions of this work is the proposal of a structure for knowledge sharing to describe a knowledge theme view. This structure presents a base structure that can be extended to include and reference more information and thus provide richer semantics by adding new elements.

This work claims that an appropriate approach to use the proposed structure for knowledge sharing is to provide a visual interface as a 3D interactive visualisation. A direct advantage of this approach is the possibility of representing structure relationships and integrate both knowledge and data source information.

The general outcomes of this research are:

- *use of a structure to represent a knowledge theme view*: conveying information to be enhanced by collaboration. The structure allows the knowledge specification, knowledge sharing and supports the visualisation generation.
- *a 3D interactive visualisation to convey structure information*: allowing the visual sharing and individual exploration of the structure for knowledge sharing.
- *proposing a generic support to knowledge for collaborative learning*: resulting in the joint use of the structure for knowledge sharing and a 3D interactive visualisation to support collaborative learning.
- *provide the means for integration knowledge and a data source in the same interface*: by giving a visual representation for the knowledge. The integration is made possible by using Information Visualisation techniques [Card et al., 1999].

The developed prototype serves to demonstrate the use of the structure and visualisation design. The prototype allows a small group of students to take advantage of sharing knowledge about a given knowledge theme view both for its discussion and to support information retrieval. The data source support is given by generating contextual searches using the structure for knowledge sharing.

The novel aspect in the thesis is the proposal of the use of knowledge to render a three dimensional interactive visualisation design, and an integrated Information Visualisation to combine data source information with the visualisation of the structure for knowledge sharing. Together these facilities provide an environment for collaborative learning support.

The system can be integrated with a data source, providing a tool for sharing and manipulating the visualised structured information as a knowledge map. This means that the system assists users in information retrieval actions within a specific knowledge theme view. The ViDESK model provides the support for more informed browse and search tactics to be undertaken by the user. ViDESK also provides support for sharing, discussing, and exploring the structure for knowledge sharing, providing an environment for collaborative learning.

1.5 Structure of the thesis

This thesis is organised in nine chapters as follows. Chapter 2 – **Cognitive overhead, information overload and collaborative learning**, provides the underlying reasons that inform the efforts to this work, giving an historic overview of trials and approaches to provide better support for knowledge sharing both for the individual and groups in a learning perspective. It also introduces information issues regarding the problems of cognitive overhead and information overload. A number of learning issues are presented to inform the development and evaluation of the prototype.

Chapter 3 – **From collaboration technologies to knowledge representation**, presents a set of concepts to be used during the work. Due to the multidisciplinary nature of the work, a number of work areas were studied. In particular, the World Wide Web, Virtual Reality, Information Retrieval, CSCL and CSCW systems, Visualisation, Information

Visualisation, graphical knowledge representations and Topic Maps are discussed. Additionally a number of graphical tools and knowledge maps are presented.

Chapter 4 **– Graphical support for knowledge sharing**, introduces the system general description to provide a broad view of ViDESK functionality. The section provides a description of the system proposal to support the work undertaken. It also introduces the general context for its use.

Chapter 5 **– A model for a visualisation for knowledge sharing**, presents the model to address the problem of sharing knowledge. The model is based on a structure for knowledge sharing to support and organise knowledge to be shared and to support the visualisation rendering. As part of the model, the Visualisation design and Information Visualisation are also presented.

Chapter 6 **– Implementing a knowledge sharing system**, introduces the prototype that implements the ViDESK model ideas. The application consists of a collaborative infrastructure that allows a small group of students to collaboratively construct a structure for knowledge sharing of a given theme and use it to support access to a Web search engine for information retrieval. The interaction is based on the use of a 3D interactive visualisation. The prototype technical solutions and its use are briefly presented. Also, a user scenario is described.

Chapter seven and eight present the prototype evaluation. Both the evaluation setting and methodology are described in chapter 7 **–** E**xperiments to evaluate the system in use**. The evaluation results are presented and discussed in chapter 8 **– Experimental Results**.

The final chapter (**Conclusions and future work**), summarises the research undertaken. The most important concepts and results are outlined and the novelty in the work is listed. A discussion on how to improve current work and new directions for further work is given. Finally a number of recommendations are made, taking into account the experience gained.

2 Cognitive overhead, information overload and collaborative learning

2.1 Introduction

In chapter 1 – **Introduction**, the thesis problem has been presented: how to share knowledge between a group of people, in particular people engaged in learning activities together. In particular, the work proposes a system for knowledge sharing to support collaborative learning in a higher education context and the use of a visualisation design to convey it.

In order to inform such a system, a number of fundamental issues must be considered as the interface issues, learning issues and information issues. These three are seen as fundamental to inform a Visualisation Design for Sharing Knowledge. The above issues contribute to the discussion of the role that Visualisation may have in the development of the next generation of user interfaces.

The motivation section introduces the potential that visualisation and virtual reality can have. In particular, a new generation of user interfaces that include emergent computer 3D facilities such as Information Visualisation and Virtual Reality systems as defended by a number of authors as [Card et al., 1998; Erickson, 1993; Benford and Greenhalgh, 1993].

The interface issues provide an historical background to inform how the use of 3D facilities can be an advantage. In particular, Bush, Engelbart and English for their visions [Bush, 1945; Engelbart and English, 1968], Hutchins and Norman concerning the collaborative aspects of the representations and the importance of representation itself [Hutchins, 1995; Norman, 1993], and by Jul and Furnas regarding the use and navigation on information spaces [Jul and Furnas, 1997].
Learning issues, who provide the notions of experiential and reflective learning [Norman, 1993], learning in an artificial intelligence perspective [Coelho, 1996], the importance of social interaction [Vygotsky, 1978], and the notion of collaborative learning [McConnell, 1994].

Information issues contribute to the discussion of the cognitive overhead and information overload problems. In particular, the contributions from Ebersole and Conklin situate the problem of cognitive overhead and characterise it [Ebersole, 1997; Conklin, 1987]. Regarding the problem of information overload, important discussions are provided by Kerka, contributing to its characterisation [Kerka, 1997], and Wurman who also introduces the related notion of understanding [Wurman, 1989].

This chapter is structured as follows:

- Section 2.2 – "Motivation", explains the aim and the motivation underlying the proposed work.
- Section 2.3 – "Interface issues". Discusses why this work and associated problems are important, feasible, and how they relate to research purposes.
- Section 2.4 – "Learning issues", introduces the concepts of learning and collaborative learning used in this work.
- Section 2.5 – "Information issues", introduces the information-related problems of cognitive overhead and information overload.
- Section 2.6 – "Final remarks", presents a number of research issues to be considered.

The perspective that Visualisation can promote the opportunity to foster user interaction and computer based human mediation is defended. The chapter ends with a proposal of the main issues to be researched in order to develop better human-computer systems.

2.2 Motivation

Information Management and information flow can be seen as critical success factors in human systems [Gouveia 1994], based on the hypothesis that if these factors are handled conveniently it is possible to improve productivity dramatically. In order to obtain such an advantage, the information system must be improved with technology that enables the information to flow and that integrates with existing information systems.

As emerging disciplines, Visualisation and Information Visualisation can be of interest. The latter can offer technologies that improve the way humans perceive and use large and complex datasets, and help manipulate information [Card et al., 1998].

The former can be introduced as the process of transforming data, information, and knowledge into visual form making use of the human's natural visual capabilities [Card et al., 1998]. It can also provide an interface between the human mind and the computer.

Moreover, Virtual Reality technology offers a great potential to represent information and a new paradigm to represent information in 3D. Virtual Reality (VR) can be considered as the delivery to a human of the most convincing illusion possible that they are in another reality [Harrison and Jacques, 1996]. This reality exists in digital electronic format in the memory of a computer. Terms related with Virtual Reality (Jaron Lanier) are Artificial Reality (Myron Krueger), Cyberspace (Willian Gibson), and, more recently, Virtual Worlds, Synthetic Worlds, and Virtual Environments as stated in [Beir, 1996].

How can we relate Virtual Reality technology and visualisation? We can consider that the visualisation goal is to represent data in ways that make them perceptible, and able to engage human sensory systems [Erickson, 1993]. As Artificial Reality makes it easier to interact with visualisations, and the user can have its own presence in a 3D space, there are more natural possibilities for manipulating 3D images. This opens the way for users to interact directly with the data, for multiple users to interact simultaneously with the same visualisation, and also act as environments to support human/human interaction [Erickson, 1993].

The impact and use of Visualisation and VR technology to visualise information, and knowledge in an education environment along with the possibility to support knowledge sharing, is the intended subject of this study. Approaches to educational systems based on well-tested and conventional techniques have suffered from limitations due mainly to:

- the complexity resulting from large amounts of unstructured information, and the difficulty of keeping pace with updating, verification, and authoring information. This affects largely human computer interaction, and no novel solutions are in sight to solve this problem.
- the complexity of co-ordinating several information sources when one tries to move to decentralised or distributed solutions does not seem to be reduced as heterogeneity, and interoperability problems arise. Further, related problems concerning user interaction remain untouched.

- the shift in information content from pure data to knowledge does not seem to fit well with conventional available systems. Knowledge changes and evolves continuously and needs to be certified, authored, and represented in various supports and dimensions.

The proposed approach in this work is to free information and knowledge from conventional and hardware-oriented supports and to ease user information management [Fairchild, 1993]. Visualisation and VR technology seems a promising start as it allows for the following improvements:

- the cost of technology is falling, and it is now becoming affordable for even small organisations;
- although the visual quality of these systems cannot, as of now, compete with traditional displays, this is not a drawback in our context;
- user interaction becomes more intuitive, and presents the possibility of extending routine work, with apparently no losses in productivity [Oravec, 1996; Barnatt, 1997];
- Visualisation and VR technologies offer new possibilities to build system applications that improve or modify radically productivity [Chorafas and Steinamann, 1995; Barnatt, 1997].

The described improvements are also valid for Computer Supported Cooperative Work (CSCW) systems. The goal of CSCW is to discover ways of using computer technology to further enhance the group work process through support in the time and place dimensions, where the focus of CSCW is the social interaction between people, and not the technology itself [Dewan, 1998].

When considering the use of VR as an enabling technology in CSCW systems, it will be possible to enhance co-operation by synchronising the focus of users' attention – the *Do You See What I See* issue [Wexelblat, 1993]. With users inhabiting a common world, this problem is avoided. The creation of a virtual environment where users can collaborate using VR technology and CSCW principles, introducing 3D representations, user embodiment and enhanced interactivity is referred to as a Collaborative Virtual Environment (CVE) [Benford and Greenhalgh, 1997a].

The essence of a CVE system is to make it possible to interact with an information space and with other individuals to share, discuss. It also allows to turn visual as much information representations as wanted.

The emphasis of this work is on the following issues:

- representation of information and knowledge in 3D spaces, where there are needed better alternatives and innovative approaches;
- creation, sharing, and modification of information and knowledge visual representation in 3D spaces;
- productivity issues related to the use of the system in an educational setting.

Why consider a learning prototype system to test these ideas? Today educational systems are in change [Gouveia, 1999b]. This can be seen as a great opportunity to apply some of the concepts regarding the ongoing research into real settings.

A European Commission document [European Commission, 1998] confirms that perspective, by stating that the access to information alone is not the answer to better education, learning and training. There is also a need for skills and tools that enable users to turn the information into knowledge. The document concludes that we are beginning to witness the evolution of the information society into the knowledge-based society.

2.3 Interface Issues

2.3.1 Use graphics as dialogue extenders

The need for better ways of representing information and dealing with the increasing complexity and volume of information for a user or a group of users is not new. These topics constitute a central issue for many research projects and are part of the expected outcomes for many others. Most of those projects follow in the footsteps of the Engelbart's Augmentation Research Centre, at Stanford Research Institute, which was set up to explore new forms of computer interaction [Engelbart and English, 1968]. A more recent proposal is given by Schneiderman's Genex which proposes a framework for an integrated set of software tools to support creativity [Shneiderman, 1998b]

Some people, such as Sutherland, propose new forms of dialogue between users and computers – a graphical dialogue [Sutherland, 1963]. Lakin also proposes a performing medium where the focus is on live manipulation of text and graphics [Lakin, 1988]. Laurel adds that "*graphical and, by extension, multisensory representations are to both physical and emotional aspects of directness in interaction. Hence, it is worthwhile to examine the role and contributions of graphic design in interface systems*" [Laurel, 1993].

Tufte introduces the roles that graphics and other visuals must follow in visualising information and conveying meaning. His books are each oriented to a specific topic: the first book focuses on introducing a graphics history and a language for discussing graphics. It also gives a practical theory of data graphics (in particular, statistical graphics) [Tufte, 1983]. The second book presents the principles of information design that are as universal as mathematics, in the author's perspective [Tufte, 1990]. The book is also about escaping flatland, this means, adding more dimensions to be represented and discuss how to represent the rich visual world of experience and measurement knowing that the world is complex, dyna mic and multidimensional. The third Tufte' book deals with design strategies for presenting information about motion, process, mechanism, cause and effect [Tufte, 1997].

Flatland is a word coined by Abbott, from an 1884 book with the same name, where he describes a two-dimensional universe in which all the creatures were flat shapes [Abbott, 1991]. The Flatland book also offers a demonstration of the difficulties of breaking out of the mental structures we use to make sense of the world, and serve as a reflective model for the use of 3D facilities in actual computer systems. This was best described by Woolley's comment about the book [Woolley, 1992]: "*How would A. Square make sense of Spaceland, the three-dimensional world occupied by the strange Sphere creature that can be experienced in Flatland as a circle that could make itself large and smaller, and that could appear and disappear at will?*".

2.3.2 The human side of technology users

When dealing with visual information representation for humans, the first issue to consider must be the individual, his/her perceptual limitations and the way he/she understands visuals. Norman defined humans as thinking, interpreting creatures, that are active, creative, social beings [Norman, 1993]. Hutchins states that cognition is socially distributed [Hutchins, 1995]. The same author adds that cognitive activity must be analysed in context, where context is not a fixed set of surrounding conditions but a wider dynamic process of which the cognition of an individual is only a part. This means that we must consider cultural factors and explicable effects that are not entirely internal to the individual [Hutchins, 1995] – introducing a socio cultural perspective.

The concept of space and its use is also important to the present study. Human cognition adapts to its natural surroundings and potentially interacts with an environment rich in organising resources. For Hutchins, human cognition differs from that of animals, primarily because it is intrinsically a cultural phenomenon. Hutchins refers to three kinds of space: the physical space, the social space and the conceptual space. It is the last one – conceptual space – that will be the focus for the present study [Hutchins, 1995].

2.3.3 Systems to support knowledge sharing

The main material each individual can use, share, and communicate which is knowledge. A precursor system like the Memex system presents as its essential feature the associative indexing which introduces the concept of creating an information space from new material and active links to existing material [Bush, 1945]. The Memex was described as an individual appliance to organise and access information.

Ted Nelson (who coined terms such as *hypertext* and *hypermedia*) introduced the Xanadu project in 1962, extending the Memex system and proposing a new type of publishing medium, allowing the creation of links between existing and new contents, including its modification. These links make possible the creation of new meanings and interpretations by elaborating dynamic structures. The proposed system can be described as a collective appliance. The system is also described by [Woolley, 1992], "*everything within the Xanadu project exists by virtue of its links with everything else, and those links are constantly forged and broken. Every reader of every text contributes to its meaning by participation in the creation of the structures that place it*". If we consider not the database implementation but a visualisation representation with an annotation linking system some of the described functionality can be achieved.

Although the Xanadu project has not been accomplished, a distributed hypermedia system – the World Wide Web (WWW or Web) [Berners-Lee et al., 1994] – with a client-server architecture has become a global system to access information. The Web content is unstructured and is continuously changing its content. It links a huge amount of information that is increasing all the time. The Web has three characteristics that make its study challenging for current research: its information is not globally structured; the information is dynamic and complex; and the huge amount of available Web information originates scaleability problems, even if we considered only parts of Web representations.

2.3.4 The direct manipulation factor

One of the important interface concepts is direct manipulation. It was coined by Shneiderman [Shneiderman, 1983] who listed three criteria for a direct manipulation system: (i) continuous representation of the object of interest; (ii) physical actions or labelled button presses instead of complex syntax; and (iii) rapid incremental reversible operations whose impact on the object of interest is immediately visible [Shneiderman, 1998a].

Shneiderman argues that the goal of direct manipulation is the creation of environments "*where the users comprehend the display, where they feel the control, where the system is predictable, and where they are willing to take the responsibility*" [Shneiderman and Maes, 1997]. He also states that the future direction for direct manipulation is information visualisation with the focus on the remarkable human capabilities in the visual domain, under-utilised by current design [Shneiderman and Maes, 1997]. This also may apply to visualisation.

The use of 3D visuals, the time and space representation, the ability to detect patterns and the representation of cause/effect relations seems to be some of the key issues in the information visualisation field. Other important issues for the current research are interaction and sharing, allowing individuals to deal with information and share its visions of it. Visualisation and Virtual reality systems may play an important role in this, giving way to new forms of interaction with information visualisations and dealing with the dynamic characteristic of information.

2.3.5 The importance of a common language

Another important issue is the context where the information sharing is done. This introduces the concepts of collaboration and co-operation and the need to consider

issues already being considered in CSCW systems. As a functional combination of VR and CSCW systems, a CVE can offer an environment where more than one user is involved with an information space. In a CVE the need for information visualisation still exists and remains as one of the components to be studied, along with others.
To share information we must deal with a common language that specifies and enables the basic communication operations to share meaning by known abstractions. This gives rise to questions about symbols and semantics, that is, communication issues.

Hutchins also proposes that when the manipulation of symbols is automated, neither the cognitive processes nor the activity of the person who manipulated the symbols is modelled. The original source domain for the language of thought was a particular highly elaborated and culturally specific world of human activity, that of formal symbol systems [Hutchins, 1995]. This way, the boundary between inside and outside became the boundary between abstract symbols and the world of phenomena described by the symbols.

Hutchins defends that "*people process symbols (even the ones that have internal representation), but those symbols are not inside the human mind, creating a distinction between cognitive and perceptual human activities*" [Hutchins, 1995]. Hutchins adds that "*the symbols were outside, and the apparatus that fell off is exactly the apparatus that supported interaction with those symbols. When the symbols were put inside, there was no need for eyes, ears, or hands. Those are for manipulating objects, and the symbols have ceased to be material and have become entirely abstract and ideational*" [Hutchins, 1995].

In cognition, based in Hutchins, we must distinguish between the tasks that the person faces in the manipulation of symbolic tokens and the tasks that are accomplished by the manipulation of the symbolic tokens. The same author presents humans, good at detecting regularities in their environment and at constructing internal processes that can co-ordinate with those regularities. They spend their time producing symbolic structures for others. Hucthins concludes by saying that "*ontogenetically speaking, it seems that symbols are in the world first, and only later in the head*" [Hutchins, 1995].

Given the multidisciplinary nature of visualisation, it is important to define the problem to study. Information works as the raw material to be used. The main area of study will be the sharing of knowledge by using visual representations to convey information about it. The main problem is *How far can 3D visual computer mediated representations be useful in helping the understanding and communication between individuals of shared knowledge?*

When dealing with representations it is rather obvious that different one can enhance the understanding level of a particular problem. The form of representation makes a dramatic difference in the ease of the task and their proper choice depends upon the knowledge, system, and method being applied to the problem [Norman, 1993].

Why consider visualisation as a research topic? We need better tools to deal with complex data sets, ill-structured and dynamic information settings that characterise actual systems – to deal with communication needs, understanding and learning problems, and cognitive overhead and information overload [Forrester, 1987]. Visual representations are more natural for humans and can be used to improve their perception to learn and as an aid for search and computation.

2.3.6 From abstraction to action

The data-information-knowledge pyramid (Figure 1) can provide a starting point to the research discussion. The higher the level, the more symbolic the abstraction. A similar pyramid is proposed by Lengel and Collins [Lengel and Collins, 1990], but designated as educational pyramid, where the information level is referred to as *ideas level*. The authors give a description for their educational pyramid: "*What education is supposed to do is to get students to see data (facts) in such as way as to inform themselves. The data in their mind are combined into information. Information is then related to other information to produce ideas in the students' minds – concepts that help explain the world. Some students combine these ideas to produce a wisdom that understands the whys and wherefores of life and truth. The aim of education is to move up the pyramid*" [Lengel and Collins, 1990].

In the lower level, *data* is considered as the base raw material to represent information [Wilson, 1997]. In a more formal definition, data is the representation of facts, concepts, or instructions in a formalised manner suitable for communication, interpretation, or processing by human beings or by automatic means [ANSI, 1982].

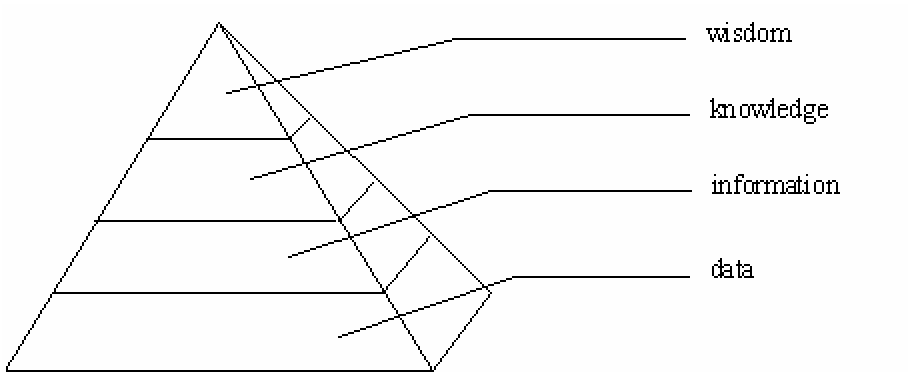

Figure 1: data-information-knowledge pyramid

Information is based on data aggregation and is considered as the material to help and support decision making or other actions [Wilson, 1997]. A formal definition is proposed by [ANSI, 1982] as the meaning that a human being assigns to data by means of the conventions applied to those data. For [Barnatt, 1997], information is the product of filtering and then processing raw data into a potentially useful form.

The knowledge level adds context and purpose orientation to the information level. Knowledge Management is an actual research topic in the Management, Information Systems, and CSCW areas. *Knowledge* stems from the analysis of information within an expert frame of reference so that it becomes attributed with actual meaning. Barnatt proposes an illustration for the data-information-knowledge progression (Figure 2) [Barnatt, 1997].

Figure 2: data-information-knowledge progression

At the top of the pyramid (Figure 1) a higher level – wisdom – is proposed as the long term material to high order structured models for representing reality. Wisdom is socially constructed and derives its value from being accepted by a group of individuals.

The knowledge which is used in a given problem domain could transform itself into wisdom and become a base to the generation of action activity [Coelho, 1996]. Cooley proposes a data to wisdom transformation, based in a signal/noise relation – Figure 3 [Cooley, 1988].

Data combined gives information. Information, placed in the appropriate context, forms knowledge. And knowledge, combined with experience, judgement and a whole range of other things, gives us wisdom [Weir, 1996].

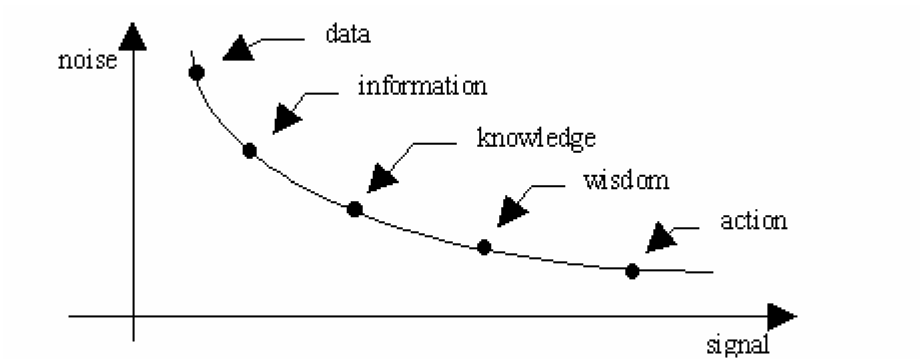

Figure 3: data to wisdom transformation

2.3.7 Information artefacts and information access

Norman proposes that external representations, especially ones that can be part of a workspace shared with others, require some sort of constructed device to support them: an artefact [Norman, 1993]. He also adds that the representations of the representations of thoughts and concepts are the essence of reflection and of higher-order thought. It is through *metarepresentations* that we generate new knowledge, finding consistencies and patterns in the representations that could not readily be noticed in the world [Norman, 1993].

As we step up to higher levels of abstraction, better cognition artefacts are needed. Engelbart proposes a useful notion of artefact as part of four basic classes of augmentation means (the others are language, methodology and training) [Engelbart, 1963]. The proposed cognition artefact in this work differs from the Engelbart notion of artefact because he considered only physical objects. This way the proposed cognition artefact is more like the Engelbart's *language* class from the conceptual framework, defined as *"the way in which the individual classifies the picture of his world into the concepts that his mind uses to model that world, and the symbols that he attaches to those concepts and uses in consciously manipulating the concepts («Thinking»)"* [Engelbart, 1963].

In particular, information artefacts are the tools for dealing with information. Concerning the designing principles for information appliances, Norman proposes three axioms [Norman, 1998]:

- *simplicity*: the complexity of the appliance is that of the task, not the tool. Make technology invisible for the user;
- *versatility*: appliances must allow and encourage novel, creative interaction;
- *pleasure*: appliances should be pleasurable, fun and enjoyable to the user.

A further important notion to be considered is the way we access and use the information. Humans access information in several different ways. If we consider the amount of information available organised into an information space, we can distinguish three access types: searching, browsing and reading [Rada, 1995].

- In the search type access, one concept is key and that concept occurs just once (or a few times) in the information space.
- In the browsing access, several important concepts relate to several parts of the information space, some are relevant and some are not.
- For the reading access, the user takes all the information space trying to match the required concepts.

Swets provides two useful definitions concerning information access: precision – fraction of the retrieved information which is relevant, – and recall – fraction of the retrieved information relevant versus all relevant information – [Swets, 1969]. If considered together with the amount of information, precision and recall provide a three dimensional criteria to evaluate information access (Figure 4).

The search access needs few parts of the information space and should be performed in a system that provides high recall and, at least, medium precision. The browse access needs several parts of the information space, also needs high recall and, at least, medium precision. The reading access needs to consider greater parts of the information space, which corresponds to an understanding task. We have an understanding problem when precision and recall are low or when we need to consider large amounts of information [Rada, 1995].

These information access types work better in small to medium information spaces where their dimension corresponds to more structured concepts with a greater number of relations between them. This way, to perform search and browsing tasks in an information space, some understanding tasks must be performed in order to learn about the information space and the amount of information, precision and recall values.

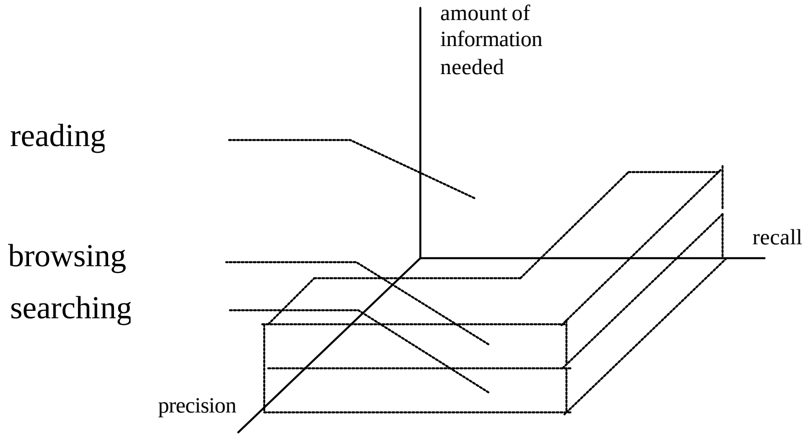

Figure 4: three-dimensional criteria for defining information access

The understanding problems can be filtered by the use of better and more abstract information visualisation schemes. The medium is important for helping in understanding tasks, like in the case of paper that can be more attractive than computerised information based on its familiarity, tangibility, and portability [Hansen and Haas, 1988].

Providing an alternative perspective for studying information access, Laura Leventhal defines navigation as "*the cognitive process of acquiring knowledge about a space, strategies for moving through space, and changing one's metaknowledge about a space*" [Jul and Furnas, 1997]. Furnas and others [Jul and Furnas, 1997], proposed a definition of some concepts related with navigation where a distinction between task (search and browse) and tactics (query and navigate) is made. This way, search is considered a task of looking for a known target. Browsing is the task of looking to see what is available in the world. The querying tactic consists in submitting a description of the object being sought to a search engine, which will return relevant content or information. Navigation is presented as moving sequentially around an environment, deciding at each step where to go next, based on the task and on the environment seen so far.

Furnas presents *map building* as one of the navigational subtasks and describes it as constructing a representation – mental or physical – with spatial structure to aid multiple route following and finding tasks [Jul and Furnas, 1997]. Apperley, Carl, Jul, Leventhal and Spence proposed a three level structure to the navigational design where the users cognitive map is based on their previous knowledge, experience and their views of the imposed structure (Figure 5) [Jul and Furnas, 1997].

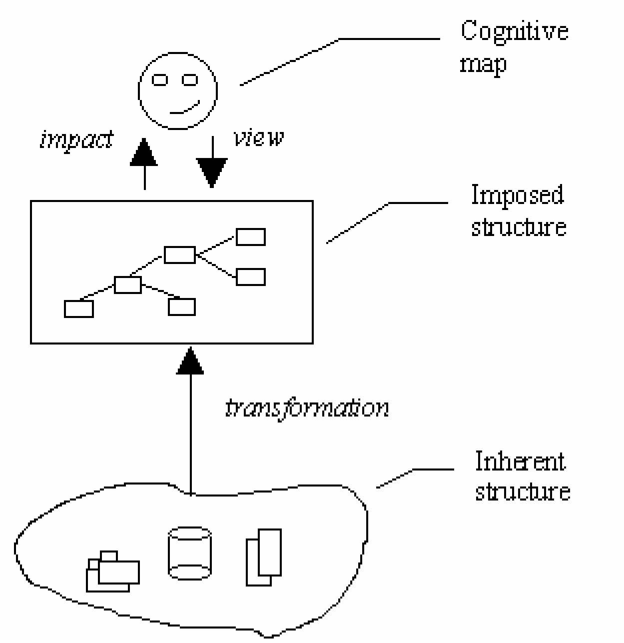

Figure 5: levels of structure for navigational design

For our purposes, the generation of cognitive map visualisations can be of interest. McAleese suggests that the concept map functions as an aid, helping the learner interpret and organise personal knowledge [McAleese, 1998]. The same author proposes the use of concept maps to the representation of knowledge and its application to support learners with external learning spaces by providing cognitive map visualisations [McAleese, 1998].

2.4 Learning issues

2.4.1 Experiential and reflective learning

The way we learn as a cognitive experience can be a result of many kinds of cognition. Norman proposes two modes that are relevant when a discussion of cognitive artefacts is made (in a human centred view): experiential and reflective learning [Norman, 1993]. The experiential mode leads to a state in which we perceive and react to the events around us, efficiently and effortlessly. The reflective mode is that of comparison and contrast, of thought, and of decision-making. The first mode is related with an expert behaviour and efficient performance, and the second, with the creation of new ideas and novel responses.

Human cognition is a multidimensional activity, involving all the senses, internal activities and external structures; this way Norman recognises that the division in only two categories of human cognition is a simplification, although useful for design purposes of human-centred systems [Norman, 1993].

Norman proposes that experiential thought *"is reactive, automatic thought, driven by the patterns of information arriving at our senses, but dependent upon a large reservoir of experience. (…) It involves data-driven processing"* [Norman, 1993]. The reflective mode *"is that of concepts, of planning and reconsideration. (…) Tends to require both the aid of external support and the aid of external people"*.

Norman suggests that the environments used to aid cognition must be designed accordingly: *"the external representations have to be tuned to the task at hand if they are to be maximally supportive of cognition. Rich, dynamic, continually present environments can interfere with reflection: These environments lead one toward experiential mode, driving the cognition by the perceptions of event driven processing, thereby not leaving sufficient mental resources for the concentration required for reflection. In the terms of cognitive science, reflective cognition is conceptually driven, top-down processing* " [Norman, 1993].

The focus on designing the action is also proposed by Laurel [Laurel, 1993]. Bodker [Bodker, 1989] adds that in performing a task, the person has a focus and a goal, this way the attention must be in the task, not in the tool. Tools must be in the background, giving a feeling of working directly on the task.

Rumelhart and Norman propose three kinds of learning: accretion, tuning, and restructuring, extending the experiential and reflective cognition framework [Rumelhart and Norman, 1978]. Accretion is the accumulation of facts, adding to the stockpile of knowledge. With the proper conceptual framework, accretion is facilitated and efficient.

Tuning is based on massive practice. It tunes the skill, shaping the knowledge structures in thousands of little ways so that the skill in early stages required conscious reflective thought ,could now be carried out automatically, in a subconscious, experimental mode.

Experimental thought is tuned thought [Norman, 1993]. Tuning is necessary to reach expert levels of performance, and then essential to maintain them.

Restructuring is about forming the right conceptual structure. Accretion and tuning are primarily experiential modes and restructuring is reflective. This third way of learning is where new conceptual skills are acquired. It is necessary to use the right tools to reflect, explore, compare, and integrate.

Hutchins proposes learning or conceptual change as a kind of adaptation in a larger dynamic system [Hutchins, 1995]. He also states that one scale of learning or changes in the organisation of cognitive systems are the opportunities for the development of new knowledge in the context of practice. Experimental artefacts provide mediation between the mind and the world. Reflective artefacts allow us to ignore the real world and concentrate only on artificial, representing worlds.

In figure 6, Coelho proposes a learning triangle, with three main learning activities and general knowledge transformations [Coelho, 1996]. This represents an Artificial Intelligence perspective of learning activities. The proposed path for handling knowledge gives the possibility to obtain solutions and more knowledge from actual situations.

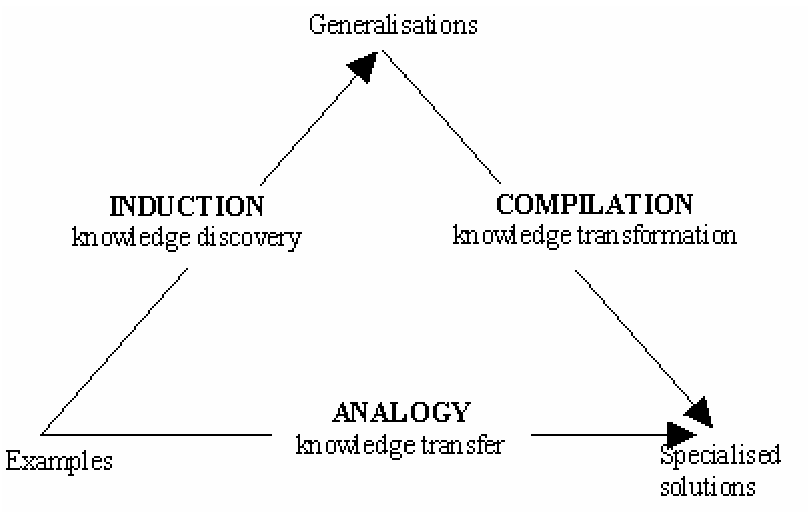

Figure 6: the learning triangle

Learning can be defined as any deliberate or directed change in the knowledge structure of a system that allows it to perform better on later repetitions of some given type of task [Fischler and Firschein, 1987]. Learning is seen by Brown and Duguid as the acquisition of knowledge [Brown and Duguid, 2000]. Vygotsky asserts that one important aspect of learning is social interaction [Vygotsky, 1978]. Fischer presents a group of assumptions about learning made in current trends in educational theory [Fischer, 1996]:

- learning is a process of knowledge construction, not of knowledge recording or absorption
- learning is knowledge-dependent; people use their existing knowledge to construct new knowledge
- learning is highly tuned to the situation in which it takes place
- learning needs to account for distributed cognition, requiring knowledge in the head to combine with knowledge in the world
- learning is affected as much by motivational issues as by cognitive issues.

When discussing learning, one important concept is the existence of *mental models*. Mental models are the images, assumptions, and stories that we have of others, organisations, our experience, and ourselves. It is through mental models that we view reality. Culture can be seen as one of the most basic mental models. Added to that is the accumulation of knowledge and experience, which brings us to the present day.

2.4.2 Collaborative learning

Schools and universities today emphasise working in isolation; however, digitalisation will encourage teamwork [Weir, 1996]. This is reinforced by [Goeller, 1998] who states that western business, social and academic culture is ruggedly individualistic; education's focus is on individual performance while employment performance assessment is based almost exclusively on individual performance. Nevertheless some experiments with group assessment are reported in the literature [Gouveia, 1998b]. To confront students with group work, teachers must explicitly teach and model teamwork including it in curricula because as Goeller states, technically competent students are actually deficient if they cannot apply that competence in a team setting [Goeller, 1998]. We can say that co-operative learning is a recent concept as a way of thinking about and conducting the educational process. Although co-operation in learning is not in itself new, the idea of "cooperative learning" as a particular system of learning is [McConnell, 1994].

Co-operation is defined by Argyle as "*acting together, in a coordinated way at work, or in social relationships, in the pursuit of shared goals, the enjoyment of the joint activity, or simply furthering the relationship*" [Argyle, 1991]. McConnell states that co-operation "*is seen as central to our everyday lives*" and "*cooperative learning is process driven*" [McConnell, 1994]. In the definition of the group, McConnell states that a human group is a collection of individuals, who have interdependent relations, and who perceive themselves as a group that is recognised by non members. Finally, group members have interdependent relations with other groups and whose roles in the group are functions of expectations (internal and external) [McConnell, 1994].

In open learning situations where there are many different simultaneous influences on the group including distributed systems and the use of virtual technologies to augment the group environment it is possible to add some influences from beyond the social structure of the group itself [Wexelblat, 1993]. Co-operative work produces information products such as decisions, design, and analysis, minimises information loss, and operates a finer level of details [Scherlis and Kraut, 1996].

What are the outcomes of cooperative learning? In their work, Johnson and Johnson looked at 323 studies and concluded that cooperative methods lead to higher achievement than competitive or individualistic ones [Johnson and Johnson, 1990]. In another study conducted by Slavin, it is reported that cooperative learning increases the positive affect of classrooms and students working cooperatively become more cooperative; they learn pro-social behaviours such as how to get on with others, how to listen and so on [Slavin, 1990]. Also, Sharan suggests that cooperative learning fosters knowledge about the learning process [Sharan, 1990].

In addition to the individualistic and competitive learning goal structures, cooperative learning can be relevant to education, learning and training, justifying the introduction of ICT that support it. When dealing with technologies some practices must be well planned especially in an environment with a great number of systems owned by multiple kinds of users. This can become even more complex as it can be stated that technology is a less stable resource than users and work practice. To complement, technology is developing fast and the users have just become aware of a potential change of the traditional work practice [Kommers et al., 1996].

Since the notion of cooperation is inherent in collaborative learning, research can also be applied to collaborative learning environments. Both cooperative and collaborative learning are built around the idea of socially constructed knowledge.

Collaborative learning can be defined as the interaction of two or more people to engage in value-creating activities based on improving, practising, and transferring learning skills both within the group and to the organisation or group of organisations to which they belong. The outcomes of collaborative learning activities are improved work performance, strategic awareness, and positive business impacts. Johnson and Johnson have shown that students in collaborative learning environments outperform students in non-collaborative environments [Johnson and Johnson, 1990].

The kinds of activities referred to as collaborative learning are tasks that students perform in groups of two or more. These tasks might include peer critiquing of papers, working together on a project or assignment, exploring content and practising skills. Knowledge is not generated in a continuous way. Its change is often characterised by alternating periods of slow movement and rapid transformation.

Information and theory help to outline an alternative paradigm and encourage individuals for further development where knowledge can be developed. Sipusic and others enumerate a collection of five theories that have been devised to explain the collaborative learning effect [Sipusic et al., 1999]:

1. the small group environment provides more time for each student to communicate. It allows more opportunities for students to ask questions and thus acquire new information;
2. during collaborative learning, students make public considerations about knowledge. The feedback from others helps group members to refine their ideas even further;
3. the social necessity to communicate their ideas requires students to articulate and elaborate their knowledge. The acts of articulation and elaboration encourage the active use of the conceptual content which, in turn, fosters learning;
4. students in collaborative groups exhibit helping behaviours – offering emotional encouragement, tutoring, sharing notes, etc. – that increase learning;
5. collaborative learning leads to increased receptivity to learning by increasing motivation and attention.

Collaborative learning needs to be distinguished from cooperative learning. Both are non-competitive forms of learning, and in both the reward structure encourages students to work together to accomplish a common end.

Cooperative learning, however, generally leaves established authority structures unexamined and untouched. The end is defined in the beginning by an instructor-in-charge, who also prescribes the means by which the goal is to be obtained and evaluates the entire exercise, without his/her own role being seriously questioned or open to significant change in the process.

Collaborative learning is comparably cooperative, but it takes all of the participants one step further: involving them in self-reflection of a kind that generally raises serious questions of "meaning" and "power" and forces them to confront issues implicit in any classroom learning regimen but rarely explicitly defined and dealt with.

Collaborative learning fosters an openness to change that enables participants to work together closely and self-critically, towards an eventual improvement of the effectiveness of their teamwork. Such a system characteristically evolves beyond cooperative and adaptive learning, learning needed to survive, and develops generative learning capabilities – a process by which participants enhance their creativity, and rationally direct their evolution.

For a class to become such a learning system, the teacher must become a collaborative member of the system without losing his/her leadership that can and must facilitate and guide the learning process. To collaborate in exploring, describing, interpreting, explaining, and providing generative knowledge about the world, it provides better human systems.

Underlying the majority of collaborative learning experiences is a distinctive set of assumptions about what learning is, and what the nature of knowledge is. Perhaps the most important of these is the assumption that knowledge is created through interaction, not transferred from teacher to student [CELT, 1994]. It follows that instructional activity must begin with students' current levels of background knowledge, experience, and understanding. It further follows that the teacher's role is to create a context in which learners can make their own progress through an active process of discovery [CELT, 1994].

The knowledge thus gained is acquired in a down-to-earth, proactively "hands-on" way. Such knowledge is empirically testable and practically useful. It can be validated through further action research; it can be codified and communicated in ways that make it accessible to those who need to use it.

2.5 Information issues

2.5.1 Cognitive overhead

Effective design of interactive information artefacts needs to take into account the cognitive experience of the end user. Key issues to be considered include coherence and cognitive overhead [Ebersole, 1997].

Interactive media authors apply theories of coherence and cognitive overhead as they relate to user comprehension. By increasing coherence – facilitating the construction of semantic relations between information units – and minimising cognitive overhead – freeing processing capacities that otherwise would have been bound by orientation, navigation, and user-interface adjustment – interactive information artefacts can increase their effectiveness [Ebersole, 1997].

For example, increasing local coherence of text-based information is achieved by using established rules of grammar and compositions, and by limiting the appearance of fragmentation [Wright, 1993]. However, to increase local coherence one needs to minimise the appearance of fragmentation. Caution should be exercised to prevent fragmentation, which causes user disorientation and confusion.

With respect to reading a *hyperdocument*, Conklin characterised cognitive overhead as "*the additional effort and concentration necessary to maintain several tasks or trails at one time*" [Conklin, 1987]. The reason for cognitive overhead lies in the limited capacity of human information processing [Johnson-Laird, 1989]. Every effort additional to reading reduces the mental resources available for comprehension Nielsen describes "overhead" and "cognitive load" as they apply to the user's experience in terms of the "look and feel" of the interface [Nielsen, 1990]. The experience, according to Nielsen, should be one of effortless navigation through the material without concern for "*what the computer will do or how to get it to do what they want*" [Nielsen, 1990]. According to Thuring, Hannemann and Haake, cognitive overhead in *hyperdocuments* often results when users are concerned about orientation, navigation, and user interface adjustment [Thuring et. al., 1995]. Dealing with what may be an unfamiliar user interface while trying to remember one's position within the document can put a load on the cognitive process, thus making less processing power available for comprehension and learning. In summary, minimising the distractions of disorientation and unfamiliarity will enhance comprehension [Ebersole, 1997].

The use of different media brings the issue of using different symbol systems to present information to the user [Ebersole, 1997]. According to Ebersole – based on [Salomon, 1979] – differences between various media are significant in two ways:

- the amount of mental translation from an external symbol system to the required internal mode;
- the kinds of mental skills invoked in the process of knowledge extraction.

Salomon perceived these differences to be of great importance with regard to their impact on the use of media for educational purposes [Salomon, 1979]. The assumption is that the increase in mental resources required for recoding results in a decrease in comprehension [Ebersole, 1997].

Two of the many important elements to consider when designing an interactive system, which will increase coherence and minimise cognitive overhead are consistency and orientation cues.

- *consistency* is achieved when the same actions result in the same effect, regardless of other variables that may have changed. A consistent interface is achieved by selecting and then following, a metaphor. The metaphor is the overarching theme that captures the form and function of the system's architecture [Erickson, 1990]. According to Lynch, a successful metaphor limits the number and complexity of rules that the user must learn for interaction [Lynch, 1994].
- *orientation* is a means to reduce cognitive overhead by using cues to aid the user's navigation through the information space of the hyperdocument. The

metaphor of space is common to the world of computer-mediated communication [Ebsersole, 1997].

Empirical studies summarised in [Dillon et al., 1994] revealed a correlation between comprehension and memory for location. One interpretation of this result is that memory for content and memory for spatial information are different aspects of the same mental representation – the user's mental model.

In summary, readability can be improved by supporting the construction of a mental model in terms of a dual approach [Bly and Rosenberg, 1986]:

- increase coherence, thus facilitating the construction of semantic relations between information units;
- reduce cognitive overhead, thus freeing processing capacities that otherwise would have been bound by orientation, navigation and user-interface adjustment.

This approach leads to a number of design problems that must be solved to support user understanding. These problems can be formulated as cognitive design issues.

In cognitive science, comprehension is often characterised as the construction of a mental model that represent the objects and semantic relations. When people interact with the environment, being people or technology, interpretative representations are developed. These representations drive performance and are mental models [Norman, 1993]. Johnson-Laird characterises mental models as incomplete, unstable, not having firm boundaries. Moreover, people's ability to control their models is limited [Johnson-Laird, 1989].

Individuals not only read for understanding, they appear to read for theme. If a relevant theme is not available, comprehension is inadequate and recall suffers. Two factors in particular are crucial in this respect: coherence as positive influence and cognitive overhead as negative influence on comprehension [Thuring et al., 1995]. Information is easier to remember when it is in an orderly state, rich in pattern and structure, and highly interconnected.

A well-defined, recognisable structure for content flow minimises the mental effort to understand content [Thuring et al., 1995]. Information is easier to process if presented in one whole piece. For example, reading on-line is slower and unpleasant. It requires much more mental effort and concentration [Thuring et al., 1995].

We can advance possible definitions for comprehension, coherence and readability. *Comprehension* is the construction of a mental model that represents objects and semantic relations described. A document is considered to be *coherent* if an individual can construct a mental model from it that corresponds to facts and relations in a possible world.
Also, *readability* can be defined as the mental effort required for comprehension. In order to increase readability the individual must be helped in the construction of a mental model. Strengthening factors that support the mental model leads to coherence; otherwise, if factors impede the construction of a mental model, this imposes cognitive overhead. *Cognitive Overhead* can be defined as the additional effort and concentration necessary to maintain several tasks or trails at one time.

Kommers and Lanzing argue that concept mapping can be used essentially as a method to regulate the ratios between fragmentation/coherence and cognitive overhead/flexibility during the students' browsing in *hyperlinked* documents [Kommers and Lanzing, 1997].

2.5.2 Information overload

Information Overload, Info-glut, *Infobog* and Data Smog are some of the names provided for the Information Age phenomena caused by the volume of information that technology now makes available. As reported by Brown and Duguid on an anonymous and ubiquitous phrase, showing how the amount of available information has increased: "*On an average weekday the New York Times contains more information than any contemporary of Shakespeare's would have acquired in a lifetime*" [Brown and Duguid, 2000].

The end of the twentieth century sees, for the first time in history, a capacity for producing information greater in scale than the human capacity to process it [Shenk, 1997]. In fact, an average worker spends half of a regular day processing documents [Owen, 1999].
However, some authors began questioning if the problem is really information overload. Paul Saffo asserts that is not the information overload that causes problems but our inability to process information [Owen, 1999]. He further states that information overload is not a function of the volume of available information but a gap between the

volume of information and the tools we have to assimilate the information into useful knowledge. A similar position is defended by [Shenk, 1997] who argues that people make the mistake of confusing information with knowledge.

[Kerka, 1997] points out that it is a misconception to think of the problem of information overload as the result of too much information; she argues that a greater problem may be an increase of no information. Information overload can also result from the multiplicity of communication channels. Unlike earlier eras, new technologies are not replacing but adding to the host of media choices [Gilster 1997].

With these multiple channels the information flow is now simultaneous and multidirectional. However, most traditional information management practices are too linear and specific. As referred by [Alesandrini, 1992] they were pipes developed for a stream, not an ocean. Both the volume and speed which information can be acquired give an illusion of accomplishment [Uline, 1996].

A key issue related to information is its usefulness. As pointed out by [Milton, 1989] a great deal of effort is used gathering the raw material – information – and almost nothing is spent on the most important job of transforming information into intelligence. Milton also suggests that it is possible to have “negative information” – that may lead to knowing less than before because it is not integrated, applied, and transformed into knowledge.

One important issue is the understanding of the relationships between data, information, and knowledge: data are raw facts and figures; information is data organised into a meaningful context; knowledge is organised data (i.e., information) that has been understood and applied [Kerka, 1997]. Wurman also asserts that the problem with information overload can be an explosion of information that lacks relevance, quality, and usefulness [Wurman, 1989]. As Kinnaman points out, we need better judgements of the quality, accuracy, and reliability of received information [Kinnaman, 1994].

According to Brown and Duguid, people may perceive overload because the information they receive does not fit into current mental models for understanding the world [Brown and Duguid, 2000]. The problem of information overload thus has both technological and human aspects. The solution as stated by Kerka has also two aspects: *technological* – create better technological tools and make better use of them and *human*

– revise mental models and sharpen the capacity for critical reflection and analysis [Kerka, 1997].

Information may be current, timely, and sufficient for the task at hand but not necessarily complete [Lively, 1996]. The goal of information seeking should be to find the answers to personally meaningful questions. It is quite consensual that a way to deal with information overload is to select and restrict what to follow and to keeping up. As pointed out by Tetzeli, dealing with information becomes easier once it is accepted as a part of life [Tetzeli, 1994].

Davidson believes that most decisions made by people are not of long-term importance [Davidson, 1996]. The same author suggests that there is no need to continue gathering information when instinct indicates that enough is known for a decision to be made. As Lenox and Walker suggest, it is more important to know where and how to find what one needs to know [Lenox and Walker, 1993]. The focus should be less on the acquisition of information than on the execution of information processes – thinking about and interacting with information.

The Internet gives the impression that the pace of change has accelerated [Kerka, 1997]. Dvorak attributes that to the fact that the Web has simply removed natural barriers between people and information they would otherwise never see [Dvorak, 1996]. Although availability is important it does not provide importance, accuracy, utility, or value to the content [Berghel, 1997], which makes availability a necessary but not sufficient condition.

Research has shown that many people feel that information gained through a computer screen is more reliable than from any other source [Breivik and Jones, 1993]. Kinnaman reports companies that published reports on computer printout paper because people were more accepting of their authority [Kinnaman, 1994].

According to Koniger and Janowitz information is valuable only to the extent that it is structured [Koniger and Janowitz, 1995]. In the World Wide Web there are not widely common structures (in fact, there are many alternative structures), which means that the medium is no longer a reliable indicator of the type of information it contains. Because there are no preconceived notions of content, new kinds of information structures are needed [Kerka, 1997]. The Internet requires the user to build content from its vast resources [Gilster, 1997].

It is possible for an individual to retrieve information – physical access – but be unable to understand it – intellectual access – [Wurman, 1989]. Factors such as time pressure and familiarity may make people rely on information sources that are immediately available and accessible, but not necessarily the best [Savolainen, 1995]. As stated by Kerka this is both a human and a technological issue [Kerka, 1997].
Current education practice emphasises navigation of information sources over critical analysis, integration, and application [Kinnaman, 1994]. Also, Lenox and Walker argue that people are not prepared to deal with information overload problems by the old educational paradigm that emphasises acquisition, access, storage, and retrieval of discrete and fragmentary information (even when computers are used) [Lenox and Walker, 1993]. McKenzie presents the exercise of questioning as the primary technology to make sense [McKenzie, 1996]. He adds that questioning converts data into information and information into insight.

According Kerka we are still using the classic information retrieval model, which attempts to find the best match between mental "boxes" – questions – and structured information "boxes" that contain the answers [Kerka, 1997]. According to Hert the use of available information sources can be compared to the following [Hert, 1994]:

- *superhighway* – learn how to drive, by using the tools;
- *cyberspace* – learn where to go, by navigating;
- *community* – critically questioning. Searching for answers of who, why, where and how information can help;
- *mine* –discover value, find and separate information and refine it into knowledge.

Shenk defends that everyone needs education more than information by saying that "*Education is the one thing we can't get overloaded with. The more of It, the better*" [Shenk, 1997]. Using information effectively requires a set of skills that includes thinking about the kind of information needed; locating the information; evaluating, selecting, and organising the information; and then using or applying it [Pappas, 1997]. Information technologies have also created a virtual flood of easily accessible information leading to a greater need for understanding the array of available sources

[Kerka, 1997]. The activities of information retrieval cannot replace the activities of reflecting on, evaluating, and synthesising the information [Uline, 1996].
The volume of information available and the many alternatives to access it are one of the causes for information anxiety [Wurman, 1989]. Information overload, fuels stress and promotes faulty thinking [Shenk, 1997] which is a strong indicator of the need for new tools to deal with it.

2.6 Final remarks

The various issues described raises the question on how we can use 3D facilities to improve user skills to deal with information. An historical perspective of efforts that could inform a system for knowledge sharing has been introduced. Also, a number of issues regarding interface, learning and information have been introduced. These issues allow to support the research of how Visualisation can provide a useful way of sharing knowledge representations as a collective supporting tool.

Applications for education, learning and training mediated by computer can be developed to test these ideas. Also, Visualisation can lead the way to better content management, information organisation and retrieval.

Among the research issues that could have been proposed, the following was identified as a valid path for research:

- dealing with the problems caused by the use of three dimensional facilities. Adding one more dimension to the traditional 2D brings a whole new class of problems to be considered;
- propose a model for knowledge representation that allows the use of visualisation in order to take advantage of 3D facilities. This must take into account the particular needs of a learning environment;
- propose 3D symbols to serve as demonstrators for a visualisation prototype that conveys information for sharing knowledge;
- use a set of enabling technologies to implement the developed 3D space for (i) individual control and (ii) sharing among users.
- select an application context where these ideas can be tested. In particular focus on the use of a learning context where a model can be proposed on which to

base users' discussion about a knowledge theme. Such a model can be represented as a visualisation.

Our assertion is that the use of 3D Visualisation techniques to develop direct manipulation interfaces will enable us, as Laurel states, to "*think of the computer, not as a tool, but as a medium*" [Laurel 1993], and thus, augmenting user learning by allowing the sharing of knowledge.

In particular, we propose a Visualisation Design for sharing Knowledge to allow the support of collaborative learning by minimising cognitive overhead and information overload.

The next chapter, chapter 3 **– From collaboration technologies to knowledge representation**, presents technologies and associated work that informed the current research and complemented the interface, learning and information issues by presenting a number of existing related systems proposals.

3 From collaboration technologies to knowledge representation

3.1 Introduction

Chapter 2 **– Cognitive overhead, information overload and collaborative learning**, discussed the motivation and a number of issues that must be taken into account to propose a Visualisation Design for Sharing Knowledge. It defends the use of 3D Visualisation techniques to develop direct manipulation interfaces to augment user learning by allowing the sharing of knowledge and to promote the opportunity to foster user interaction and computer-based human mediation.

In particular, we propose a Visualisation Design for sharing Knowledge to allow the support of collaborative learning by minimising cognitive overhead and information overload.

This chapter continues by discussing related research areas that are important for the conducted work. The effort involved in studying a Visualisation Design for Sharing Knowledge involves a number of concerns that can be informed by issues relating to the World Wide Web, Information Retrieval, and Virtual Reality. This is the case of Kerckhove who proposes the World Wide Web as a "my-way medium" [Kerckhove, 1996], of Rijsbergen who introduces important notions such as precision, recall and weighted keyword description [Rijsbergen, 1979], and of Cadoz who advances virtual reality as a reality medium [Cadoz, 1996].

Other technology areas are presented that have influenced the conducted work, such as Computer Supported Cooperative Work that Wexelblat relates with virtual reality [Wexelblat, 1993]. Also considered, has been Computer Supported Collaborative Learning, McConnell defends its potential which allows a group of people to work in complex ways, augmenting the group environment [McConnell, 1994]. Some of the current developments of Virtual Environments and Collaborative Virtual Environments are reported by several authors [Benford and Greenhalgh, 1997a; Chen and Gaines, 1997]. Also, Visualisation and Information Visualisation have been analysed, in particular, the works of Tufte who provides a general discussion of interactive graphics

[Tufte, 1997] and presented by Card and others where a structured view of information visualisation techniques is provided [Card et al., 1999].

The chapter includes a section that discusses graphical knowledge representation issues and ends up with how these technologies can inform the design of a system to share knowledge and support collaborative learning. In particular, the work of Novak and Gowin [Novak and Gowin, 1984], and of McAleese [McAleese, 1998] is important to relate such graphical representations to learning.

This chapter is structured as follows:

- Section 3.2 – "Related technologies", where issues concerning the World Wide Web, Information Retrieval and Virtual Reality are presented.
- Section 3.3 – "Enabling group interaction", a number of technologies related with group support are described, such as CSCW, CSCL and CVE. These were chosen because of their potential for supporting learning activities.
- Section 3.4 – "Using visuals to convey information", describes two areas that use graphical facilities to convey information – visualisation and information visualisation – that can be useful to develop a system for sharing knowledge to support collaborative learning.
- Section 3.5 – "Knowledge sharing issues", provides an introduction to graphical knowledge representation and sharing issues, with particular reference to an educational context.
- Section 3.6 – "Final remarks", closes the chapter by summarising how the above technologies can be used to propose a system for the sharing of knowledge to support collaborative learning.

This chapter is organised in order to develop the requirements of a system for dealing with the sharing of knowledge in a higher education context, proposing a visualisation design to support collaborative learning by minimising cognitive overhead and information overload (as discussed in chapter 2).

3.2 Related technologies

3.2.1 World Wide Web as a development lab

The World Wide Web, also known as WWW or Web, began in August 1990 by Tim Berners-Lee and Robert Cailliau. The Web authors submitted a proposal at CERN – the European Laboratory for Particle Physics, in Geneva – where they worked in the computer science department [Berners-Lee et al., 1995].

Particle physics research often involves collaboration between institutes from all over the world. Berners-Lee had the idea of enabling researchers from remote sites right across the world to organise and pool information together. But far from simply making available a large number of research documents as files, which could be downloaded, he suggested that they could be linked in the text files themselves. This way, reading one research paper, could quickly display part of another paper, which held directly relevant text or diagrams. Documentation of a scientific and mathematical nature would thus be represented as a "web" of information held in electronic form on computers across the world [Raggett et al., 1996].

The Web is a large-scale distributed hypermedia network based on a client-server model, with a wide range of services and standards. It can be seen as a global information system. The organisation that co-ordinates all the standardisation efforts, formed in October 1994, is the World Wide Web Consortium – *http://www.w3.org/Consortium/* , headed by Tim Berners-Lee. Since 1990 the Web has gained world-wide acceptance and every day more people in the world use, publish and work with this information system.

WORLD WIDE WEB ISSUES

The World Wide Web is a major information base and it can be considered as a digital library. However, this huge hypermedia repository seems unreliable (with many misses: document not found), information lacks context (Where am I? Can I trust this information?), and there are also navigation problems (Where should I go next?). The Web is vast, growing rapidly, and filled with transient information. According to 1996 figures, at 50 million pages with the average page online for only 75 days [Kahle, 1997], the turnover is considerable, and the number of pages is reported to double every year. In 1996, there where about 400,000 Web sites with an estimate total data of 1,500 GB and a change rate of 600 GB per month [Kahle, 1997]. A more recent study by Lyman and Varian estimate that the Web has 1 billion pages with a rate of growth rate of 7.3 million per day. In 2000, there where 1 billion web-connected documents representing 19 Terabytes of information [Lyman and Varian, 2000]. Efforts are being made to introduce semantics into Web pages that can be used to help retrieve the information – metadata – one example is the initiative in the education field [Wantz and Miller, 1998].

Nielsen refers to the Web as a "*linking medium*" [Nielson., 1996a]. The major goal that motivated the Berners-Lee work with the Web, was trying to support better ways of helping groups of people work together [Berners-Lee, 1995]. Berners-Lee adds that his vision for the web is "*less of a television channel and more of an interactive sea of shared knowledge*" [Berners-Lee, 1995].

The Web is an ideal environment to be used as a testing platform due to its minimal investment cost, technology availability, opportunity to use real users and data availability settings. This is also complemented with well-documented protocols and reliable technology to be used for development.

Berners-Lee lists among others, the following needs for Web development [Berners-Lee, 1996], which continue to be valid:

- share knowledge – with semantics;
- notification of change built into web;
- structuring aids;
- better access control – how can we trust Web for information availability;
- integration with audio, video and whiteboard;
- enabling group editors;
- distributed simulation environments with object manipulation capabilities.

Web services have become more accessible, allowing users to easily publish their own information on the Web. This way, as technology is better integrated into the classroom and educational settings, the Web is being used more as an instructional tool [Aken and Molinaro, 1995; Gouveia, 1999a].

One aspect to be considered is Web design, where certain interfaces issues need to be considered and adapted for this medium. Nielson discusses the use of narrative structures [Nielson, 1996a] and reports a list of top ten mistakes in Web design [Nielson, 1996b]. Some specialised companies propose a general issues list for Web design such as those provided by McKim [McKim, 1996a; McKim, 1996b; McKim, 1996c]. Some authors also propose methodologies for Web development [December, 1998]. Also, Rosenfeld and Morville propose an Information Architecture for the World Wide Web to support the design of large-scale Web sites [Rosenfeld and Morville, 1998].

Kerckhove asserts that the Internet is not just a medium [Kerckove, 1996]. He adds: "*it is not a one-way medium. It is not even a two-way medium. It's a «my-way» medium. When everything and everybody is on-line, everybody has a word to say about what's worthy to read, hear, see, watch and do on-line. That means that the user, not the producer of information is in the driver's seat*" [Kerckhove, 1996].

3.2.2 Information retrieval

As defined by Baeza-Yates and Ribeiro-Neto, information retrieval (IR) studies the retrieval of information from a collection of written documents [Baeza-Yates and Ribeiro-Neto, 1999]. The retrieved documents aim at satisfying a user information need. According to Rijsbergen an information retrieval system does not inform (i.e. change the knowledge of) the user on the knowledge theme of his/her inquiry [Rijsbergen, 1979]. It merely informs as to the existence (or non-existence) and whereabouts of documents relating to his request.

Information retrieval is different from data retrieval (DR) as summarised in Figure 7. An IR system is more concerned with retrieving information about a subject than with data that satisfies a given query [Baeza-Yates and Ribeiro-Neto, 1999]. In an information retrieval system the retrieved objects might be inaccurate and small errors are likely to go unnoticed. An information retrieval system must make an attempt to interpret the contents of the information items – documents – in a collection and rank them according to a degree of relevance. The notion of relevance is important and the primary goal of an information retrieval system is to retrieve all the documents, which are relevant while retrieving as few non-relevant documents as possible [Baeza-Yates and Ribeiro-Neto, 1999].

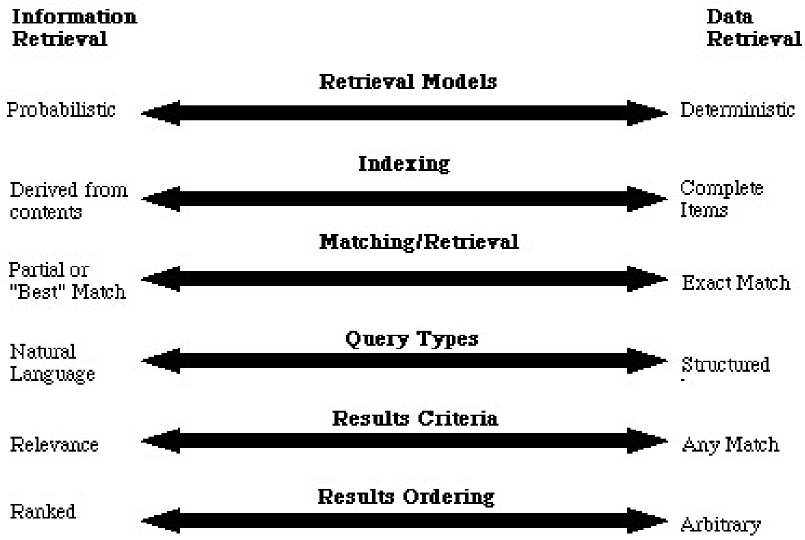

Figure 7: information versus data retrieval

Much of the research and development in information retrieval is aimed at improving the effectiveness and efficiency of retrieval. Efficiency is usually measured in terms of the computer resources used such as storage and processing time [Rijsbergen, 1979]. Efficiency should be measured in conjunction with effectiveness to evaluate the benefit in terms of unit cost. Effectiveness is commonly measured in terms of precision – ratio of the number of relevant documents retrieved to the total number of documents retrieved – and recall – ratio of the number of relevant documents retrieved to the total number of relevant documents (both retrieved and not retrieved) [Rijsbergen, 1979].

The approach to document representation pioneered by Luhn used frequency counts of words in the document text to determine which words were sufficiently significant to represent or characterise the document in the computer [Rijsbergen, 1979]. As a result of this approach, a list of keywords is derived for each document. In addition the frequency of occurrence of these words in the body of the text could also be used to indicate a degree of significance. This provided a simple weighting scheme for the keywords in each list and made available a document record in the form of a weighted keyword description. It has become common practice in the IR literature to refer to descriptive items extracted from text as *keywords* or *terms.* [Rijsbergen, 1979].

3.2.3 Virtual reality

Virtual reality (VR) is a technology that provides visual based virtual environments. Chorafas and Steinamann treat VR as a new generation of solutions that address multimedia, direct end-user interaction, the ability to visualise one's ideas, and user-activated visual programming processes[Chorafas and Steinamann, 1995].

There are several introductory papers on virtual reality available on the Web, most of them describe VR technology as a mix of hardware devices and software techniques [Isdale, 1993; IMO, 1995; Beir, 1996].

Chorafas proposed that VR brings change in three levels [Chorafas and Steinamann, 1995]: at the strategic level, with the emergence of the virtual organisations; at the implementation level, where the change will be in the way we work (the virtual office); at the tactical level, where interactive 3D graphics play an important role along with artificial intelligence artefacts and object orientation.

McGreevy sees VR as "*a display and control technology that can envelop a person in an interactive computer-generated or computer-mediated virtual environment*" [McGreevy, 1993]. The same author proposes VR as a technology that "*creates artificial worlds of sensory experience*", or immerses the user in representations of real spatial environments that "*might otherwise be inaccessible by virtue of distance, scale, time, or physical incompatibilities of the user and the environment*" [McGreevy, 1993].

Cadoz presents the idea that humans interact with the real world through the use of machines. This way the computer (as a machine) represents a reality medium and it is through it that humans interact with reality. According to this perspective, the user has only an invoked environment (and not reality), with which he/she interacts directly. A resulting interaction with the real world is accomplished via computer interaction [Cadoz, 1996]. This perspective is presented in Figure 8.

Chorafas and Steinamann sees the essence of virtual reality as a multimedia environment within the user's reach. As stated in [Beir, 1996], VR can be seen as "*the delivery to a human of the most convincing illusion possible that they are in another reality, where this reality exists in digital electronic form in the memory of a computer*" [Chorafas and Steinamann, 1995].

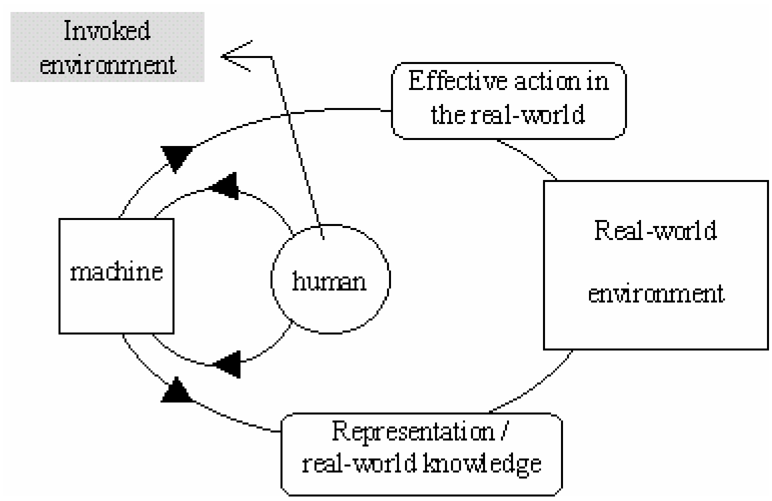

Figure 8: the human and the real world through a machine [Cadoz, 1996]

Also, VR can be considered as an enabling technology in the sense that it can bring new metaphors for interaction between human and machines. A metaphor – for information technology – is used to create things that people and machines can understand. As Chorafas and Steinamann refers, VR "*is a metaphor of the real world*" Chorafas and Steinamann, 1995]. Spatial information analysis and handling requires the use of three cognitive spaces: haptic, pictorial and transperceptual. VR facilities are also proposed as an add-on to enhance user ability to explore and visualise data in a Geographical Information System (GIS) [Neves et al., 1997].

Among the potential applications for VR are education [Harasim et al., 1995] and Information Visualisation [Chorafas and Steinamann, 1995; Fairchild, 1993]. Harasim and others, also discuss the importance of simulation, as used by the US Army, which uses among the biggest applications already developed, for education [Harasim et al., 1995]. Biocca sees VR as a cognitive technology capable of creating cognitive environments that might free the human mind by enhancing its operation [Biocca, 1996].

Fahlén defined the TelePresence from the MultiG project as distributed virtual reality. Fahlén states that "*TelePresence is about visualisation, interaction and distribution. The visualisation is done in a simulated 3D-world where the interactive manipulation is done by the use of interface units that have more degrees of freedom than a conventional keyboard and mouse can supply in a practical way*" [Fahlén, 1991]. The same author adds that within the MultiG TelePresence system "*certain objects and processes have an obvious visual representation. But how should we visualise abstract* *things that have no «natural» visual appearance? (…) There is a great potential for combinations of this new technology and conventional data processing*" [Fahlén, 1991].

Weets defined a virtual environment (VE) as a setting where the user has a sense of presence in, and is able to navigate around, a computer generated three dimensional environment, and can interact with that environment in real-time [Weets, 1993]. A virtual environment may also be defined as an advanced, intuitive, and user transparent man/machine interface. Other names for VEs, according to Weets, are proposed as VR, Virtual Worlds, Cyberspace and Artificial Reality.

Rosenblum and Cross discuss the impact and applications for VR, concerning the research and technology issues faced in constructing virtual environments [Rosenblum and Cross, 1997]. Concerning the use of VEs in an educational context, Osberg proposes a guide for developing virtual environments [Osberg, 1997]. One such virtual environment that takes advantage of the VR technology is the NICE project, which provides a supportive virtual learning environment where exploration and experiential learning is promoted [Roussous et al, 1997]. Although the NICE project has been developed to be used with children, the built systems show how to combine constructionism, narrative and collaboration in a virtual learning environment [Roussos et. al, 1997].

According to William two assumptions are made concerning constructivist theories [William, 1997]:

- students construct their own understanding of what they are learning. This can be achieved by interacting with their learning environments, using knowledge and skills that they already have, to experiment and make sense of new experiences;
- knowledge construction is collaborative. Meaning is constructed socially, and where there is disagreement about what something means, negotiation occurs [Vygotsky, 1978].

McLellan defends that VEs are good places for students to construct knowledge [McLellan, 1996]. William adds that students learn by interacting and experimenting, often iteratively, with virtual objects and phenomena as they do with real phenomena or phenomnena represented in other ways [William, 1997]. However William alerts for the need of using VEs with different strategies from the ones implemented in the classroom.

3.3 Enabling group interaction

3.3.1 Computer Supported Cooperative Work

An area that contributes to the development of systems to enable group interaction is Computer Supported Cooperative Work (CSCW). As stated by Greif, CSCW has emerged as an identifiable research field focused on the role of the computer in-group work [Greif, 1988]. One of the primary CSCW characteristics pointed out in Agostini and Michelis has been its interdisciplinarity as a research field, involving people from both computer and human sciences [Agostini and Michelis, 1997]. A CSCW system must provide means to yield solutions to problems such as how a group of people can collaborate using computers, How people plan to work together using the computer as a medium, How group work must be redefined to take advantage of computers. For Greif the focus on helping people work together is the unifying theme of CSCW [Greif, 1988].

Agostini and De Michelis propose general requirements that new CSCW systems should meet as completely as possible [Agostini and Michelis, 1997]: openness, multimedia continuity, contextualisation and integration of communication and action added to personalised and selective workspaces interfaces. Additionally, Wexelblat provides two principles of CSCW [Wexelblat, 1993]:

- co-operation is not a separable activity. This means that any computer support to be used must fit into the normal users' work pattern;
- CSCW applications must allow people to cooperate by overcoming barriers of space and time, which may lead to a discussion of time-space functionality.

One important factor in CSCW applications is the degree of collaboration awareness, that Wexelblat [Wexelblat, 1993] defines as the degree to which knowledge of, and support for, the co-operative activity has been designed specifically into the application. Wexelblat was also among the first to propose virtual reality as an enabling technology for CSCW.

CSCW as a study area can be considered as a sub-topic within the broader field of Information Systems [Checkland, 1997]. With the use of Computer Supported Cooperative Work systems one can expect to extend the study of learning environments to work environments.

Checkland states that a CSCW system implies four items: a group of people; their would-be co-operative activity: an organisational context of some kind and technology supporting the group activity [Checkland, 1997].

Marmolin and Sundblad propose the Collaborative Desktop where a number of tools designed for supporting collaboration are presented making use of direct manipulative human-computer interfaces [Marmolin and Sundblad, 1991]. The proposed tools are a team map (visual overview of members activities), a telephone exchange (for establishing connection between members), an answering machine (similar to real world answering machines), a whiteboard (for exchange and drawing of graphic messages), and a tool for asynchronous and synchronous collaboration on writing documents.

Marmolin and Sundblad demonstrated how a collaborative environment could be designed and implemented based on three principles: a tool approach, a room metaphor and an electronic hallway metaphor [Marmolin and Sundblad, 1991]. These authors also describe a model named *The Knowledge Net*, with four layers, as a CSCW environment for distributed design. The model base layer is the Knowledge Base, the second layer, the basic communication services, the third layer, the CSCW tools, and the last layer, the task, as a pre-defined combination of tools.

Crow, Parsowith and Wise give an overview of the more important issues in the CSCW area, presenting an interview with Dourish, Greenberg, Grudin and Rogers [Crow et al., 1997]. An early discussion of requirements for a CSCW platform is made by Schmidt and Rodden [Schmidt and Rodden, 1992]. CSCW systems can also be extended to deal with coordination issues like the ones reported in the Maurer paper that summarises the results from the conference WET ICE 96 [Maurer, 1996].

A number of applications are useful to inform the present work; Twidale, Rodden and Sommerville present the Designers' NotePad (DNP) as a supporting tool for collaborative dialogues and report the influence of the interface on usability and effectiveness of the system that use short text fragments positioned two dimensionally and supported by graphical notations such as links, shapes and colour use [Twidale et al., 1993]. A further tool is gIBIS which provides support for design and planning discourse, proposing graphical various views of information such as a graph structure visualisation, an index window, a control panel and an inspection window [Conklin and

Begeman, 1988]. The gIBIS tool is an example of an Issue-Based Information System (IBIS) [Rittel and Webber, 1973], that handles problems, that cannot be solved by a traditional approach. These problems lack a definitive formulation and the only way to understand them is to provide a solution – the problem space cannot be mapped out without understanding the solution elements [Conklin, 1987].

To help design CSCW systems that offer a better support of co-operative activities, the developers can use workplace studies [Plowman et al., 1995], and in particular ethnography, which provides ways to gather information from field studies of co-operative work and organisational analysis [Hughes et al., 1994]. The Project Report for a CSCW Symposium gives a framework of methods for the design of a CSCW system [SYCOMT, 1996].

Araujo, Dias and Borges propose a summary of existing approaches to support the development of cooperative software into four different aspects: group memory; awareness; communication; and coordination [Araujo et al., 1997]. Greenberg discusses real time distributed collaboration, defining terms such as *telepresence* and *teledata*, and presents a concept map groupware application [Greenberg, 1998]. Greenberg also refers to important issues to be considered for this type of system.

3.3.2 Computer Supported Collaborative Learning

One of the dimensions that must be preserved in the context of Open and Distance Learning (ODL) is the interaction between students as an essential learning requirement [De Meuter, 1998]. This is also valid for education and learning activities. Some technologies have the potential to satisfy co-operation requirements and interaction demands. One of these, more oriented to education, is Computer Supported Collaborative Learning (CSCL).

Ramage presents a discussion of the nature of co-operation and cooperative systems in [Ramage, 1999]. McConnell adds that people working co-operatively in CSCL environments do work in groups and that these groups work in complex ways [McConnell, 1994]. In open learning situations where learners conducted their learning, there are many different simultaneous influences on the group including distributed systems and the use of virtual technologies to augment the group environment.

Considering that, it is possible to add some influences from beyond the social structure of the group itself [Wexelblat, 1993].

Co-operative and collaborative work produce information products such as decisions, designs, and analysis, minimises information loss, and operates at finer levels of detail [Scherlis and Kraut, 1996]. However, Dillenbourg makes a clear distinction between co-operation and collaboration: *Co-operation* can be considered as the work division between participants with which one is responsible for a part of it, and *Collaboration* is based on an agreement between participants to resolve one problem in a unified and co-ordinated way [Dillenbourg, 1996].

Slavin states that co-operative learning increases the positive effect of classrooms, and students working co-operatively become more co-operative; they learn pro-social behaviours such as how to get on with others, how to listen and so on [Slavin, 1990]. In addition to the individualistic and competitive learning goal structures, co-operation is of interest to education, learning and training, justifying the introduction of Information and Communication Technologies (ICT).

Internet and ICT based ODL are rapidly gaining popularity and importance as a means of providing Lifelong Learning (LLL) [Ask and Haugen, 1998]. Use of new technologies such as CSCW and VR can enhance collaboration, foster knowledge representation and provide a multimedia environment allowing the development of systems that provide vicarious experience [Leclercq et al., 1998].

These technologies also provide means with which to augment the teaching and learning skills of all the users involved, creating new forms of interaction, dynamic information representation and relations within the learning community in multiple time/space alternatives. Shneiderman and others discuss the emergent patterns of teaching/learning in electronic classrooms, based on their own experience [Shneiderman et al., 1998]. One such example is given by the use of the Web as a support for student assessment in a collaborative style [Gouveia, 1998b].

Komers and others discuss the impact of using telematics for collaborative learning and relate it to more ideological changes in educational settings, such as situated learning; distributed knowledge and constructivism [Kommers et al., 1996]. Psycho-pedagogical studies in the educational field have shown that students can learn better by managing, manipulating and organising the information on their own [Ronchi, 1998].

3.3.3 Collaborative Virtual Environments

A concept that is used frequently is cyberspace. Gibson coined the term, in 1984 as a name for a virtual environment [Gibson, 1984]. Cyberspace had a significant influence on both theorists and designers of virtual reality systems [Moulthrop, 1993]. According to [Tomas, 1991], cyberspace is a "*post-industrial work environment predicated on a new hardwired communications interface that provides a direct and total sensorial access to a parallel world of potential work spaces*".

Benedikt provides a more useful definition for our purposes [Benedikt, 1991] when he states: "*Cyberspace is a globally networked, computer-sustained, computer accessed and computer-generated, multidimensional Artificial, or «virtual» reality. In this reality, to which every computer is a window, seen or heard objects are neither physical nor, necessarily, representations of physical objects but are rather, in form, character and action, made up of data, of pure information*".

This cyberspace definition can be used to foster existing Campus Wide Information Systems (CWIS) environments with the support of information technology [Deden, 1998]. One example of such an environment is available at Fernando Pessoa, University at Portugal, characterised in [Gouveia, 1998a]. Considering the Fernando Pessoa environment, it is possible to propose a service that could evolve as described by Benedikt [Benedikt, 1991]. Such projects focus on representation of information and knowledge as virtual objects that can be manipulated by users. Laurel proposes a useful definition for the use of the adjective "virtual" as "*describing things (worlds, phenomena, etc.) that look and feel like reality but that lack the traditional physical substance*" [Laurel, 1993]. The same author adds that a virtual object "*may be one that has no real-world equivalent, but the persuasiveness of its representation allows us to respond to it as if it were real*" [Laurel, 1993]. Lévy asserts that "virtual" is related with potential rather than actual existence and "*it's a mode of being which expands the process of creation*". The same author adds that the term "virtual" is being used towards actualisation without undergoing any form of effective or formal concretisation, where actualisation implies the production of new qualities, a transformation of ideas that feeds the virtual in turn [Lévy, 1998].

A Collaborative Virtual Environment (CVE) gives the opportunity to implement and assess the validity of the described concepts. A CVE system is defined by Benford and Fahlén as a "*cyberspace meeting point*" [Benford and Fahlén, 1993], which allows several people to interact through their computers in order to obtain a common goal. A CVE involves the use of distributed virtual reality technology to support group work. Benford and Greenhalgh, presented two conditions for a system to be considered a CVE: the provision of simultaneous multi-user access to a virtual reality system and explicitly consider and support the needs of users who wish to work together [Benford and Greenhalgh, 1997a].

One important aspect in this kind of system is the existence of a virtual space that Trefftz defines as an immaterial world, which allows distance interaction for several users via a set of networked computers [Trefftz, 1996]. He also states that the interaction can be accomplished from an exchange of written ideas in a 3D space with the possibility of movement and voice exchange. In a more open definition, systems such as the Multi-User Dungeons (MUD) and Internet Relay Chat (IRC) are included. Both of the systems are discussed as well as their social implications [Rheingold, 1993; Oravec, 1996; Sudweeks et al., 1998].

However both perspectives (strict and open definitions of CVE) share the point that each user needs to be aware of other users. In fact, Benford and Greenhalgh stated that the essence of CVEs is given by the users being explicit represented to each other within a shared space [Benford and Greenhalgh, 1997a]. For Rodden, a CVE can be stated as shared spaces in the machine, that are inhabited by users who are also represented in the space. Rodden adds that these environments are already realised in a number of stable technologies such as the MUDs and MOOs, for 2D, and Distributed VR environments, for 3D [Rodden, 1997].

Benford and Greenhalgh reported three main reasons to develop a CVE [Benford and Greenhalgh, 1997b]:

- support for natural spatial social skills which offer a more natural style for human interaction;

- inherent scalability, to address the interaction of a large number of users;
- applicability to co-operative spatial tasks, where current VR-applications offer design support that can be extended to support collaboration.

In Benford and others, a discussion of user embodiment is provided [Benford et al., 1995a]. It states that user embodiment means the provision of users with appropriate body images so as to represent them to others and also to themselves. Billinghurst and others discuss the Shared Space concept, where a form of overlaying the real world and computer-generated world in a setting that augmented reality must be implied to include open shared workspace paradigms [Billinghurst et al., 1998]. The same authors describe two pilot studies, which imply that wearable may be able to support 3D collaboration, and that users perform better with these interfaces than immersive collaborative environments [Billinghurst et al., 1997]. Smith proposes that CVEs can extend the *What You See Is What I See* – WYSIWIS – abstraction by the use of shared interfaces, and presents a model to manage the use of subjective views in CVEs [Smith, 1996].

Tennison and Churchill report the impact and usage of Virtual Environments for semantic structuring of an information space and as a means for collaboration between users of information systems [Tennison and Churchill, 1996]. They conclude as preliminary results that virtual environments can be used to present a metaphorical instantiation of an information resource and, also, that information retrieval is facilitated by the use of virtual environments. In other experiments with 2D and 3D visualisation settings for networked information, results showed that three times as much information can be perceived using a head coupled stereo view when compared with a 2D view [Ware and Franck, 1994].

An introduction to Collaborative Virtual Environments is provided by Benford and Greenhalgh, which includes topics such as awareness and the spatial model of interaction, scooping presence and network scalability, space, place and mixed realities [Benford and Greenhalgh, 1997a]. A CVE system brings some of the recent research into groups and co-operative settings together with the promising potential of 3D representation and interaction. It also merges the results obtained by research in the CSCW area and virtual reality technology.

IMPLEMENTATION ISSUES FOR VIRTUAL ENVIRONMENTS

Classification schemes can be developed when considering a CVE as an immersion tool. We can classify from the user interface perspective where we can identify text-based interfaces and virtual reality interfaces. Some examples of the former type are the traditional MUD and IRC systems (although these cannot be considered strictly as pure CVE systems). Examples of the virtual reality interfaces are the Distributed Interactive Virtual Environment (DIVE) which provides a general development environment [Carlsson and Hagsand, 1993] and the MASSIVE-2 system, from Nottingham University [Benford and Greenhalgh, 1997b].

Osberg proposes a four-step process and discusses related project management issues to develop virtual environments for use in learning settings [Osberg, 1997]. A discussion of multimedia user interfaces, considering virtual environment and ubiquitous computing is given by Feiner, where some of the advantages of using 3D facilities are discussed [Feiner, 1996].

In order to support communication, we need to specify links between parts. As Araujo, Dias and Borges state, communication among group members depends upon the existence and the potential of these links [Araujo et al., 1997]. These links include mechanisms for message exchange, electronic meetings and discussion forums. Different approaches to support communication can be identified. One of these approaches is based on shared workspaces. In shared workspaces participants share a common area where they express ideas and build products. Shared workspaces are the most used resources for co-operative interaction support. As discussed by Rodden this information-sharing model to support collaboration involves the use of conferencing facilities, real-time conferencing systems, desktop and multimedia conferencing and electronic meeting systems [Rodden, 1993]. Benford [Benford et al., 1996] classifies shared spaces into four types: media spaces; spatially oriented video conferencing; collaborative virtual environments, and telepresence systems.

An alternative way of classifying CVEs is by their application: some examples are computer games and VR CVEs. The latter are designed as supporting medium to a large number of users with virtual representations. A virtual world can have many users represented but also can contain autonomous agents whose behaviour is controlled by a computer program [Zyda et al., 1993].

Some of the challenges for using CVEs in higher education are the need to incorporate video, stabilise the platform on PCs, and provide a managed set of services and Campus Building Facilities [Rodden, 1997].

A detailed discussion of the implementation issues for virtual environments is presented by Brutzman [Brutzman et al., 1995]. An early introductory discussion on the software required for developing virtual environments is given by several authors [Zyda et al., 1993; Macedonia et al., 1995]. One example of a protocol implementation for network communication in a distributed virtual environment is the use of an updateable queue [Kessler and Hodges, 1996].

An early project concerned with distributed collaborative environment, the MultiG, proposed the need for further study of 3D interaction, virtual worlds and the potential of telepresence as computer-human interfaces [Pehrson et al., 1992]. The same author proposes a classification of generic collaborative tasks into four categories:

(i) conferencing, including exchange of experience and knowledge between two or more team members, concerning issues such as briefing, negotiation, idea generation and problem solving;

(ii) co-working, including any activity for synchronous or asynchronous co-production;

(iii) information exchange, such as the exchange of documents or other information structures;

(iv) management, such as the need for co-ordination and supervision, including scheduling and planning.

Some of the technical issues in developing CSCW systems relate to the support for collaboration, discussed by Rodden [Rodden, 1992a; Rodden, 1992b]. Smith and Rodden present the development of a simple mechanism that enables dynamic support for tailoring user interfaces for use in shared interfaces [Smith and Rodden, 1994].

Chen and Gaines develop a model of virtual co-operative interaction through the Web and make a comparison between groupware and socioware [Chen and Gaines, 1997]. Many research groups make the development of a groupware system over the Web: Chen and Gaines described the *InterConnect* prototype, in which interface issues are explored. Connectivity problems and difficulties of interaction using Web browsers are described by Cavalcanti and others [Cavalcanti et al., 1996].

Other systems use a browser's bookmark facility as a basis for an information sharing system [Susaki and Muramoto, 1998]. Dieberger proposes the use of Web browsers combined with a textual MOO to create an information rich spatial interface, named *Juggler* [Dieberger, 1995]. The Web can also be used to support constructivist models of education, as in the case of the *Henre* project [Lambert and Walker, 1995], where the extension to normal Web pages is made using CGI scripts, creating workspace tools and workspace connections.

The Web can also be used as a distribution medium for content, as described by Martinez and others, where an environment is proposed that supports interactive presentations to distributed audiences over the Web [Martinez et al., 1997]. Somers and others proposed, based on usability studies, guidelines for Web interface design [Somers et al., 1997]. The paper presents a field study with data from a real-time collaboration setting.

Two systems that enable collaboration over the Web are *BSCW* and *Habanero*. The Basic Support for Cooperative Work (BSCW) is based on the idea of a shared workspace that enables a group of users to organise and coordinate their work. The shared workspace is a repository of information, accessible to workgroup members using a user/password authentication scheme [Bentley et al., 1997]. The Habanero Framework or Application Program Interface, is a collaborative framework and set of applications that provides methods to create or convert existing applications into collaborative applications [Chabert et al., 1998].

3.4 Using visuals to convey information

3.4.1 Visualisation

As stated by Hamming, "*The purpose of computing is insight, not numbers*" [Hamming, 1962]. Using visual representations of data to provide information is a well-established field. Abstract displays of information (such as graphs and plots) are a recent invention (around 1750-1800) [Tufte, 1983].

As considered by Card and others, visualisation is the use of computer-based, interactive visual representations of data to amplify cognition [Card et al., 1999]. Wood and others assert that visualisation is a collaborative activity and propose the existence of a Computer Supported Collaborative Visualisation (CSCV) field [Wood et al., 1997].

Jern discusses the existence of a third-generation GUI paradigm: the Visual User Interface (VUI). The same author presents a number of characteristics that a VUI must have [Jern, 1997]:

- picture-centric user interface;
- direct interaction – exploration and navigation;
- graphical object selection and data probing;
- close connection to data;
- object-oriented focused graphics;
- control of geometry resolution;
- direct engagement of the user.

Vision is the highest bandwidth human sense [Uselton, 1995]. Humans are good at scanning, recognising, and recalling images. Visualisation takes advantage of human perceptual abilities [Johnson-Laird, 1993]. If we consider the dictionary definition of the word "visual", we obtain several definitions relating to information gained through the human eye. However, an alternative dictionary definition suggests the conveyance of a mental image. If we now look at the dictionary definition of "visualisation", we see in one case that visualisation is "*the power to process and forming a mental picture or vision of something not actually present to the sight*". These definitions allow us to consider that a visualisation can result from input to any combination of the human senses, which is not restricted to "visible" images.

Visualisation can be seen as a process with six steps, as represented in Figure 9. The enumeration of the proposed steps is adapted from Uselton [Uselton, 1995]. Uselton states that Visualisation extends the graphics paradigm by expanding the possible input. In particular, data analysis is a process of reducing large amounts of information to short summaries while remaining accurate in the description of the total data [Yu, 1995].

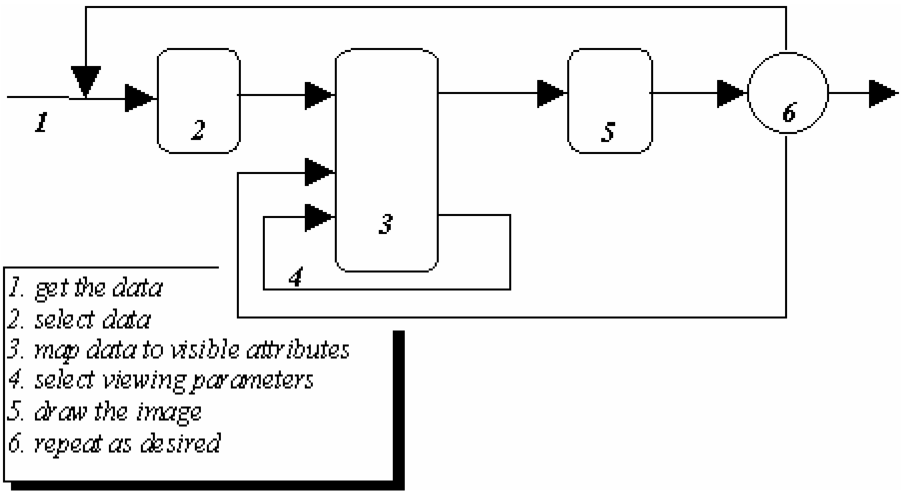

Figure 9: the visualisation process

One particular graphical application use is in statistics. Yu proposes a framework for understanding graphics based on the idea of balancing summary with raw data, and analyses ten different visualisation methods for multivariate data [Yu, 1995]. The author concludes that the use of colour in statistical graphics has long been neglected but this tends to change due to the availability of better hardware, changing the type of graphics that can be created and used. He also proposes the process of visualisation as an adjustment of noise and smooth (blocking understanding or facilitating it).

An extension of graphics is the concept of interactive displays of information. The Interactive Graphical Methods are defined as the class of techniques for exploring data that allow the user to manipulate a graphical representation of the data [Eick and Wills, 1995]. The interactive graphics are also referred to as *direct manipulation* graphics or *dynamic graphics*.

Eick and Wills list a number of areas in which interactivity significantly improves static displays, such as: clarity; robustness; power; and possibility [Eick and Wills, 1995]. The purpose of an interactive graphical display is to use graphical elements to encode the data in such a way as to make patterns apparent and invite exploration and understanding of the data by manipulating its appearance. Both Tufte [Tufte, 1997], and Eick and Wills present a general discussion of interactive graphics.

Making good visualisations requires consideration of characteristics of the user and the purpose of the visualisation. Knowledge about human perception and graphic design is also relevant [Uselton, 1995]. According to Eick and Wills a good display must include the following three characteristics [Eick and Wills, 1995]:

(i) it should be obvious as to what is being displayed;

(ii) it should focus attention on the data;

(iii) it should indicate scale and location of the data.

Cleveland gives an ordering of the difficulty of decoding visual cues, starting with the easiest ones: position along a common scale; position along identical, non-aligned scales; length; angle; area; volume; colour hue; colour saturation; and density [Cleveland, 1985].

In the DARPA's Intelligent Collaboration & Visualisation (IC&V) program, aimed at enhancing collaboration between teams through distributed information systems, one of the specified key challenges is to develop team-based visualisation software for sharing views, and in particular, visualising abstract spaces [IC&V, 1997]. DARPA describes research challenges in mapping real objects to data about them; methods for augmenting real spaces with superimposed information that adds value, and the more difficult problems of developing techniques to support visualisation of abstract N-dimensional spaces, where there is a need to develop methods for representing abstract information spaces and for navigating such spaces [IC&V, 1997]. Turner and others described a 4D symbology (3D symbols plus time-dependence) for battlefield visualisation where data come from real-time sensors and from simulations and are positioned in a high-fidelity 3D terrain [Turner et al., 1996].

3.4.2 Information Visualisation

Andrews defines Information Visualisation as the visual presentation of information spaces and structures to facilitate their rapid assimilation and understanding [Andrews, 1997]. In the same document, the author provides details of a collection of Information Visualisation related Web resources. Young reports on three-dimensional Information Visualisation [Young, 1996]. This report provides an enumeration of visualisation techniques and a survey of research visualisation systems.

McCormick and DeFanti define Information Visualisation as the transformation of the symbolic into the geometric [McCormick and DeFanti, 1987]. Bertin proposes Information Visualisation as an augmentation to intelligence in helping find the artificial memory that best supports our natural means of perception [Bertin, 1967]. The main goals of Information Visualisation are related to aiding the human in analysis, explanation, decision-making, exploration, communication, and reasoning about information [Card et al., 1999].

Visualisation offers a support structure (such as spatial or graphical representations), for pattern finding, change detection, or visual cues to help reasoning about large datasets and multiple and heterogeneous information sources. These factors are also reasons for the need to develop cognition artefacts that use information visualisation techniques [Norman, 1998]. More specifically, it is possible to summarise that visualisation should make large datasets coherent and present huge amounts of information compactly; present information from various viewpoints; present information at various levels of detail (from the more general overviews to fine structure); support visual comparisons; make visible the data gaps; and tell stories about the data [Hearst, 1998].

Three main perspectives can be considered for visualise information in 3D [Buscher et al., 1999]:

- using the properties of information objects and defining rules for their distribution in space – VIBE [Olsen et al., 1993], BEAD [Chalmers and Chitson, 1992] and Q-PIT [Colebourne et al., 1996];
- visualisations of hypermerdia-link based systems – [Card et al., 1991];
- human-centred tools, allowing people to structure and display information in electronic spaces – [Benford et al., 1997].

An example of an information visualisation system is the Populated Information Terrains (PIT). The PIT concept aims to provide a useful database or information system visualisation by taking key ideas from CSCW, VR and database technology. A PIT is defined as a virtual data space that may be inhabited by multiple users. One particular characteristic is that users work co-operatively within data [Benford and Mariani, 1994]. Moreover, VR-VIBE was designed to support the co-operative browsing and filtering of large document stores [Benford et al., 1995b].

Computers facilitate access to large datasets, interaction, animation, range of scales, precision, elimination of tedious work, and new methods of display [Hearst, 1998].

An overview of graphical visualisation is made by Ware, where the main issues with visualisation techniques are listed as: space; time; stability; and navigation, based on the hierarchy notion [Ware, 2000]. A paper collection presenting an overview of classical visualisation techniques (pan and zoom, multiple windows, and map view strategy), and *focus+context* techniques (fish-eye, hyperbolic browser, cone-trees, intelligent zoom, *treemaps*, and magic lens) is given by Card and others [Card et al., 1999]. Beaudoin and others introduce a novel approach – *Cheops* –, and a discussion of strengths and limitations of *focus+context* techniques (to which the *Cheops* approach belongs) [Beaudoin et al., 1996].

One of the application areas for Information Visualisation is Scientific Visualisation, where applied computational science methods produce output that could not be used without visualisation. This happens because huge amounts of produced data require the high bandwidth of the human visual system (both its speed and sophisticated pattern recognition), and interactivity adds the power [Uselton, 1995]. Visualisation systems provide a single context for all the activities involved from debugging the simulations, to exploring the data, and communicating the results.

Other information visualisation application area is the Software Visualisation, defined as the use of "*the crafts of typography, graphic design, animation, and cinematography with modern human-computer interaction technology to facilitate both the human understanding and effective use of computer software*" [Price et al., 1994]. By computer software, Price, Baecker, and Small intend to include all the software design process from planning to implementation. These authors present taxonomy for systems involved in the visualisation of computer software.

Chen discusses the use of information visualisation and virtual environments, presenting the *StarWalker* virtual environment [Chen, 1999]. For research opportunities, Uselton points out, among others, the need for new interaction tools and techniques; new mappings of data to visual attributes; new kinds of visuals, and automatic selection of data or mappings [Uselton, 1995]. Hearst reports that a lot of the new information visualisation methods have not been evaluated [Hearst, 1998].

3.5 Knowledge sharing issues

3.5.1 Knowledge sharing

One of the issues concerning knowledge management is knowledge sharing [Clare and Detore, 2000]. Knowledge Management is a strategy that turns an organisation's information into greater productivity, added-value, and increased competitiveness [Nonaka and Takeuchi, 1995]. Many authors assert that without an underlying culture that embraces knowledge sharing, learning and change is a natural part of each individual's work efforts in an organisational context, only short term gains are produced [Davenport and Prusak, 1998; Sveiby, 1994].

People create knowledge that directly impacts other people. A large portion of this knowledge takes the form of intangible but highly valuable know-how, experience and common sense. However, such expertise is rarely disseminated across a group: people in an organisation do not know who can help them to solve their problems, resulting in redundant work, wasting of time and loss of productivity. This also occurs when people exchange valuable information via meetings, e-mails, and phone calls. Most of the information exchange remains undocumented and therefore unusable by others. This effect is also a result of most of the times, information exchange activities result from informal interaction. Knowledge sharing problems are compounded as the group grows and has a longer existence. For all the reported information exchange problems, making available and needed information easily accessible can be a solution.

Two types of knowledge can be defined: explicit knowledge and tacit knowledge [Clare and Detore, 2000]:

- *explicit knowledge* is knowledge that is in some way articulated, documented or captured. Knowledge is often made explicit when based on policies, procedures, instructions, standards and results, and is readily communicated, often through written documentation. Textbooks, memos, e-mails, and even conversations contain explicit knowledge.
- *tacit knowledge* includes all the primary and derivative people-based knowledge assets in the organisation. It is represented by individual or group experience and expertise. Tacit knowledge is used for understanding, problem solving and gaining of perspective. It is personal and rarely documented.

A number of questions can be asked concerning the knowledge sharing in an organisation context:

- How often is time wasted thinking about a business problem when someone within reach already has the answer?
- How often is it not known whom to ask a business-related question among partners or suppliers?
- How difficult it is to find an up-to-date document that answers business-related questions?

Within education, learning and training, similar questions can be asked. In particular, taking advantage of knowledge sharing can enhance group-learning activities. Networks of knowledge sharing, community Web sites and other tools allow the promotion and support of the storage, access, brokering, and sharing of knowledge within and across organisations and groups. Among solutions that foster knowledge sharing are events that combine virtual and face-to-face interactions, allowing people to connect globally in ways that are far more powerful than other types of gatherings. There is a need to design workspaces to maximise team and individual productivity, knowledge sharing, innovation, as well as to seamlessly integrate physical and virtual space to support knowledge sharing.

Again, these ideas can also be used to promote knowledge sharing in a higher education context, with students and teachers forming groups to satisfy their knowledge needs and promote knowledge sharing events. Additionally, knowledge construction can take place using similar techniques to those used for knowledge sharing. Mercer asserts that we rely on others to help develop our understanding and learning in an educational context, and this depends on how knowledge can be jointly created and shared [Mercer, 1995].

The Gartner Group proposes a number of categories to help in understanding and evaluating technologies for knowledge management [Logan, 2000]:

1. Storage mechanisms for explicit knowledge such as document repositories;
2. Access to existing information, such as search engines and classification tools;
3. User-interface tools that offer tight integration of presentation techniques;
4. Products that address the issue of capturing tacit knowledge;

5. Collaboration support, traditionally by e-mail and extended with synchronous or real-time collaboration tools;
6. Decision support, including business intelligence;
7. Development platforms: both general-purpose and specialised for applications such as portal development.

For knowledge sharing, concerning the present work, categories 3, 4 and 5 are considered as related to graphical knowledge representations, since they focus on user interface issues, address the issue of capturing tacit knowledge and promote collaboration support. Although the use of graphical representations can help to support knowledge sharing, other approaches are possible as the one defended by Neches and others, which use knowledge based systems that rely on Artificial Intelligence techniques [Neches et al., 1991].

3.5.2 Graphical knowledge representations for education use

COGNITIVE MAPS AS HUMAN INTERNAL REPRESENTATIONS

A cognitive map is a mental map that supports navigation through the world. The concept was studied by people looking into the behaviour of animals when they moved from one location to another.

Concerning the knowledge that people need to have to move around, Thorndyke and Hays-Roth propose two types of knowledge: Route Knowledge and Survey Knowledge [Thorndyke and Hays-Roth, 1982]:

- *Route Knowledge* is knowledge that results from getting around. If someone provides directions to his/her house, he/she is using Route Knowledge.
- *Survey Knowledge* is knowledge that enables us to understand the general spatial relationships that are involved. This is applied when we indicate that the house is north of the Museum.

Cognitive maps that are constructed by people as mental maps tend to be biased by the person constructing them. Such a mental map is a map that has been filtered by our personality. With it we can justify things that do not readily fit in our concept of the universe.

Mental maps are also related to images and concepts, and these, with the way individuals think about them: Damasio defends the identification of mental images with temporarily time-locked activity in multiple neural regions (people perceiving images for thinking purposes) [Damasio, 1994], and Clark includes the identification of concepts with distributed, context-dependent patterns of neural activity [Clark, 1993]. These two perspectives provide support for the idea that such mental maps can be of help to identify and take advantage of concept and image representation for knowledge sharing support.

MIND MAPS

Mind Maps were proposed by Buzan [Buzan, 1974]. They are designed to help expand our mental capacities. The author asserts that Mind Maps can be used to promote clear thinking about concepts and ideas where relationships are visualised and manipulated in a more natural way than the case of the linear note taking. Buzan proposes a group of seven laws to develop Mind Maps: use images, use words, connected lines with associated words, one word per line, use colours and allow for creativity to take place [Buzan, 1974]. The author also proposes a technique to develop Mind Maps called MMOST (the Mind Map Organic Study Technique). Two main sections comprise the MMOST technique: preparation and application. Each of these sections is divided into four additional sub-sections. Figure 10 presents an example of a Mind Map on the uses of Mind Maps [Buzan, 1974].

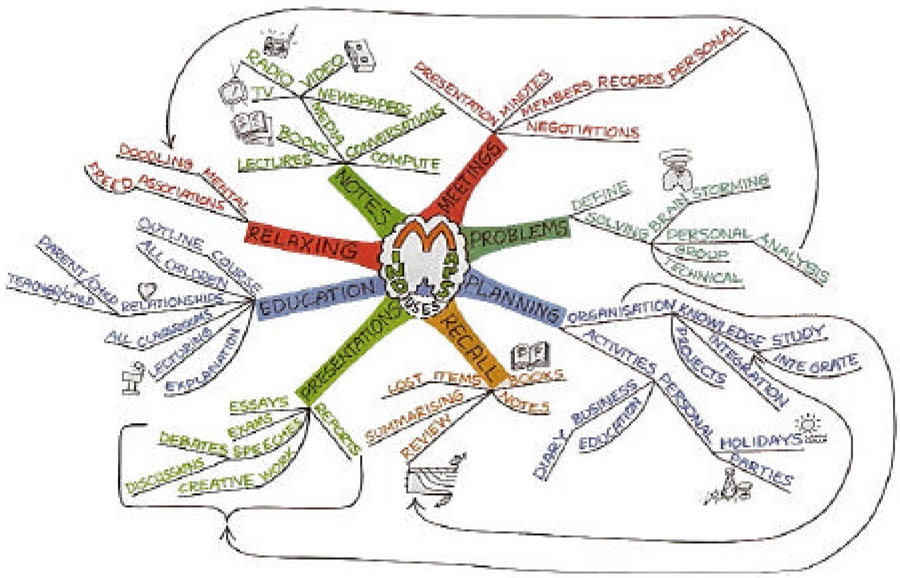

Figure 10: A Mind Map on the uses of Mind Maps [Buzan, 1974]

Mind Maps can be described as having a central word or concept. Around the central word it is possible to draw 5 to 10 main ideas that relate to that word. Taking each of those child words, and again drawing 5 to 10 main ideas to relate to each of those words [Buzan, 1974]

CONCEPT MAPS

Concept Maps provide a visual representation of knowledge structures and argument forms. They provide a complimentary alternative to natural language as a means of communicating knowledge [Gaines and Shaw, 1995].

Concept Maps are diagrams that help students see how words or concepts are related to one another. In most cases, Concept Maps begin with a brainstorming session in which students are encouraged to make associations with the main topic or concept presented. Students are actively engaged in using their prior knowledge, as well as new concepts and experiences that have been provided, to develop Concept Maps, both individually, or in small groups.

Novak and Gowin develop the concept mapping technique [Novak and Gowin, 1984]. This work was based on Ausubel's ideas that stressed the importance of prior knowledge in learning new concepts [Ausubel, 1963]. Novak and Gowin add that meaningful learning involves the assimilation of new concepts and propositions into existing cognitive structures [Novak and Gowin, 1984].

Concept Maps have been widely applied for education in evaluating students learning [Gaines and Shaw, 1995]. Figure 11 presents one example of such Concept Maps from [Novak and Gowin, 1984]. Because Concept Maps have any number of concepts they often require a network representation.

A further example of Concept Maps is proposed by Toulmin who developed a theory of scientific argument based on them [Toulmin, 1958].

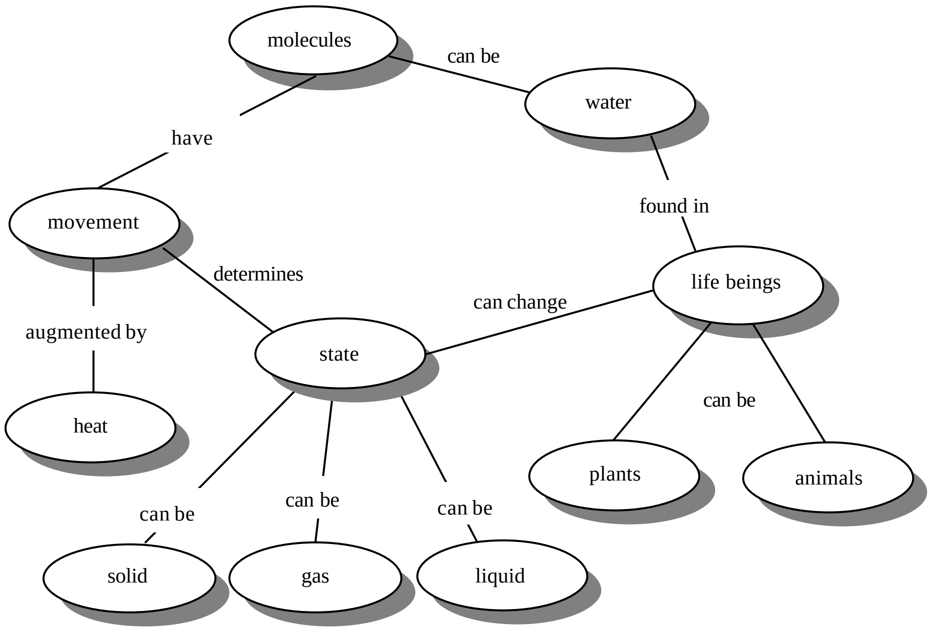

Figure 11: a Concept Map example from [Novak and Gowin, 1984]

As defended by Kommers and Lanzing, concept mapping is a method to regulate the ratios between fragmentation/coherence and cognitive overhead/flexibility during the student's browsing of hypermedia documents [Kommers and Lanzing, 1997]. The same authors add that Concept Maps can be used as:

- a *Design method* to be used as a structural scaffolding technique for the development of hypermedia;
- a *Navigation device* for students who need orientation while they explore information domains such as hypermedia documents;
- a *Knowledge elicitation technique* to be used by students as they try to articulate and synthesise their actual states of knowledge in the various stages of the learning process;
- a *Knowledge assessment tool* to enable students to diagnose their own level of understanding and to detect misconceptions.

CONCEPT DEFINITION MAPPING

The strategy, proposed for developing student vocabulary, provides an illustration – mapping – of the attributes of key concepts [Schwartz, 1988]. Students are asked to think beyond the essentials of what a word is and what it is not. The use of the Concept Definition Mapping promotes the analysis of a word from multiple perspectives. This strategy is aimed to foster students' understanding of semantic relationships between words while aiding in their recall. Figure 12 presents an example of a Concept Definition Mapping.

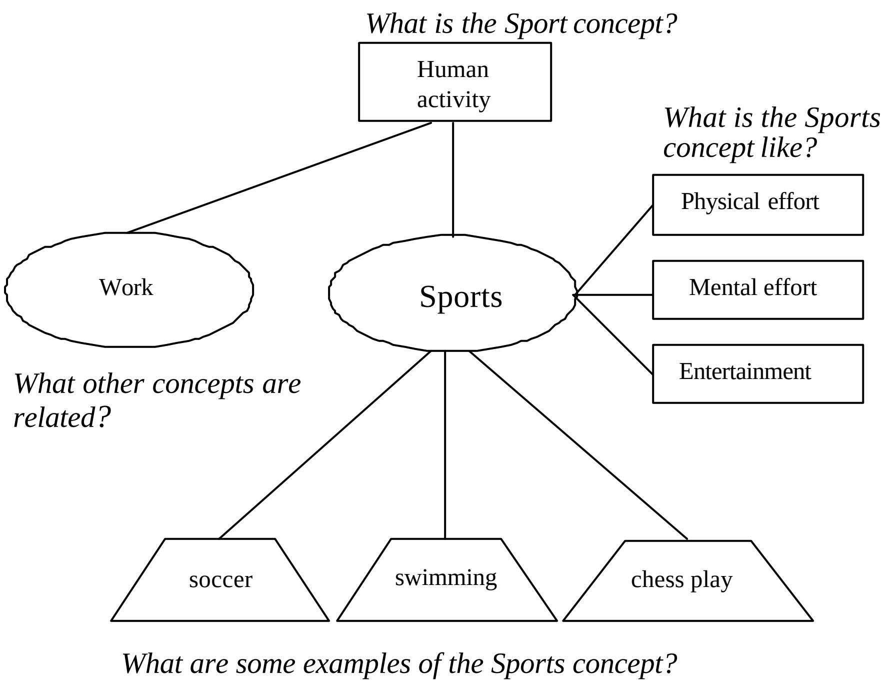

Figure 12: a Concept Definition Mapping example

To use this technique the following steps should be followed:

1. Propose an initial Concept Definition Map;
2. Discuss the questions that the Concept Definition Map should answer: What is it? What is it like? What concepts are related? What are some examples of it? What are its essential characteristics? What makes it different?;
3. Use additional familiar vocabulary terms to complete the Concept Definition Map;
4. When the map is finished, ask for a complete definition of the concept;
5. Allow for continuous map improvements along with the learning process related to the concept.

SEMANTIC MAPS

Semantic Maps are a strategy for graphically representing concepts. Semantic Maps portray the schematic relations that compose a concept. It assumes that there are multiple relations between a concept and the knowledge that is associated with the concept. Thus, for any concept there are at least these types of associations:

1. *class*: the order of things (selection) the concept falls into;

2. *property*: the attributes that define the concept;
3. *example*: exemplars of the concept.

Semantic Maps are used also to identify techniques that describe a variety of strategies designed to show how key words or concepts are related to one another through graphic representations [McAleese, 1998]. These techniques are also known as idea mapping or word webbing. Mapping can be used for teaching vocabulary, for textual patterns of organisation, for improving note taking and for creative thinking skills. For teaching vocabulary, learners are asked to create their own unique semantic networks of association with a given text. Figure 13 shows an example of the use of Semantic Maps, given by [Zaid, 1995].

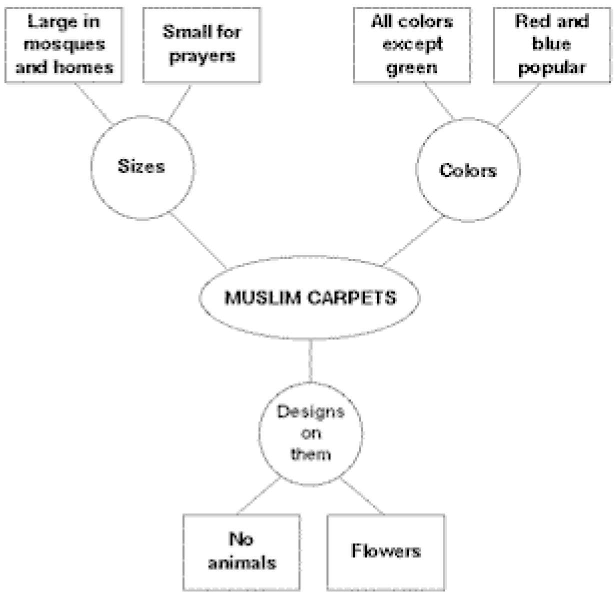

Figure 13: example of a Semantic Map about Muslim Carpets [Zaid, 1995]

A general procedure to develop a Semantic Map is by having a group discussion. In a situation like this, it is almost inevitable that the three types of concept associations – class, property and example – will emerge.

The major purpose of a Semantic Map is to enable students to organise their prior knowledge into formal relations and thus provide themselves with a basis for understanding what they are about to read and study. Comprehension can be thought of as the elaboration and refinement of prior knowledge. Semantic Maps provide a graphic structure of knowledge to be used as the basis for organising new ideas as they are understood [McAleese, 1998].

Within the Artificial Intelligence field, a similar Semantic Map representation is known as Semantic Networks. A Semantic Network focuses on the graphical representation of relations between elements in a domain. It is a non formal knowledge representation [Findler, 1979].

Hanf was among the first to propose the development of a Semantic Map procedure designed to improve the teaching of study skills [Hanf, 1971]. However, the notion of Semantic Maps is older and based on Ausubel who claimed that background information was a necessary prerequisite to the addition of new concepts and vocabulary [Ausubel, 1963].

Ausubel asserts that when individuals are presented with new concepts, these concepts will not be explicitly understood until they are linked in a meaningful way to pre-existing concepts [Ausubel, 1963]. Similarly, reading theorists have likened the process of reading comprehension to relate the new and the unknown [Pearson and Johnson, 1978].

Gathering the several uses of Semantic Maps it is possible to consider them as:

- a technique for increasing vocabulary and improving reading comprehension;
- a means of improving the teaching of study skills;
- a framework for identifying the structural organization of texts;
- a means of teaching critical thinking skills;
- an assessment technique;
- a computational scheme to support reasoning in intelligent systems.

During the process of developing Semantic Maps, it is possible to identify what is in and what is outside of students level of awareness with regard to core ideas and supporting details [Fleener and Marek, 1992]. This can provide diagnostic information, which can help lead a group in an appropriate direction. The final phase of Semantic Maps development comes when students are asked to recall the details of a text and to discuss and graph new information onto their pre-existing maps.

Fleener and Marek assert that Semantic Maps are useful for evaluating students' increase in understanding throughout the learning cycle. They go on to state that the identification of misunderstandings early on allows teachers to redirect students misconceptions. As an assessment tool, Semantic Maps revealing beyond students' perceptions also allow to relate misunderstandings of core ideas, concerning the three phases of the learning cycle – exploration, conceptual invention, and expansion – [Fleener and Marek, 1992].

SEMANTIC MAPPING FOR CONCEPT FORMATION

Semantic Maps are also used as visual tools to encourage readers to access their prior knowledge regarding concepts, to examine and understand components of new concepts, and to relate them to previous knowledge, for concept formation. A method for using Semantic Mapping for Concept Formation might be as follows:

1. write the subject or concept in the middle of a chart;
2. students brainstorm and record a list of related words – the bigger this list is, the better;
3. group the words into categories in the form of a web or map;
4. explain the reasoning behind word groupings to the group of students.

Figure 14 presents an example of a Concept Mapping for Concept Formation. The group discussion is critical to building understanding and provides a solid foundation for the reading that will follow.

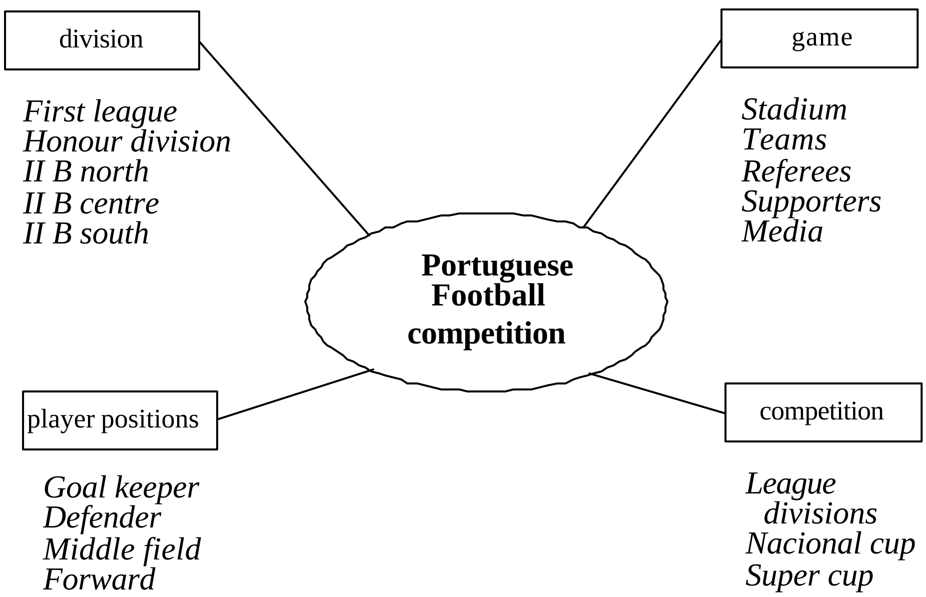

Figure 14: Semantic Mapping for Concept Formation example

Every individual has a chance to compare with others its notions while gathering further background knowledge. Discussion is also valuable as an opportunity to fill in knowledge gaps or to attempt to eliminate misconceptions about the topic.

KNOWLEDGE MAPS

A Knowledge Map can be defined as a visual representation of a knowledge domain according to criteria that facilitate the location, comprehension or development of knowledge. Knowledge mapping is a systematic approach to improve the understanding of knowledge through visualisation. This may include the previous types of maps already introduced.

A Knowledge Map represents concepts and their relationships (such as a hierarchy, a taxonomy or a network). It is a navigational aid that enables a user to position him/herself on the desired concept and follow links to relevant knowledge sources. It models explicit information about peoples' processes, and their information objects, and the relationships between them.

Hall defines Knowledge Maps as a method of displaying text in a two dimensional, spatial, node link network. The same author states that one of the basic assumptions of the model is that structural properties of the map format activate spatial processing channels which during subsequent retrieval, the structural information stored within spatial schemas can act to cross reference detailed information during recall [Hall, 1996].

Hall shows that Knowledge Maps can be an effective tool for enhancing acquisition of text materials relative to a more traditional format (like text) and concludes by saying that objective cognitive outcomes are mirrored in student subjective rating of concentration and motivation, showing that affective outcomes could also be considered [Hall, 1996].

Kesik proposes Knowledge Mapping as a process rather than a content. He adds that science is knowledge, and that science extends in a knowledge landscape like land in a geographic landscape. The same author asserts that order is funded in patterns, patterns in similarity, similarity in likeness, and likeness by comparing perspective; if these do not fit in to our patterns we seek to explain, to understand, and to know why not or why for [Kesik, 1996].

Kesik defends that maps can be considered both descriptive tools and prescriptive guides which may be referred to as a *tool-guide* function. A Knowledge Map is a representation of what we know of science. It provides a recording of the patterns that have been recognised and in turn situates these patterns as elements to expand patterns. As maps can serve both as a descriptive tool and a prescriptive guide, they are unique resources to help to know what to know when we do not know what to know [Kesik, 1996].

TOPIC MAPS

Topic Maps and Knowledge Maps are related, but not equivalent, concepts. A Topic Map is a particular type of Knowledge Map, one that describes a semantic network of relationships between concepts. Topic Maps are an ISO standard for describing knowledge structures. Topic Maps allow us to [Logan, 2000]:

- represent objects and provide a way of navigating them;
- enable the structuring of unstructured information;
- deploy information sets in different environments with different requirements.

Topic Maps enable users to capture knowledge about information resources: what is in them, where they are and how to reach them. The Topic Map paradigm is a technology that can be used to improve access to information. According to the Gartner Group, Topic Maps will be an adopted technology for the use of portal and search engines [Logan, 2000].

The international standard for Topic Maps [ISO/IEC, 1999] defines Topic Map syntax. It allows the creation of a model for an area of knowledge. The model takes the form of an XML document-type definition. A Topic Map works by layering associated information over an information set. It is a knowledge representation paradigm that allows knowledge structures to be modelled and then linked to information sources.

The strength of Topic Maps is that they allow indexing and data modelling information to be maintained separately from the information that is indexed or modelled [Logan, 2000]. Every user can therefore have a particular Topic Map representing a view into the data [Pepper, 1999].

Topics have a flexible definition: they can be anything that the user is interested in and their subject is what they are about. Topics also have names, which identify them for their users. Names are declared, much like data values for variables. Topics become the constituent parts of Topic Maps. They can be thought of as multidirectional links, pointing to all of their occurrences. The idea is that the link will aggregate everything about a given subject. Topics and their links are networks of meanings defined by the user [Biezunski, 1999].

Topic Maps are groups of named information objects around topics and the relationships between them. These relationships are called *associations*. The topics and their associations form networks when they are parsed. The links between the nodes of the network can be traversed to find related information and used to create networks of knowledge and information [Biezunski, 1999].

Topic Maps are not constrained by a particular structure. They may be object-oriented, hierarchical, ordered or unordered. Any number of Topic Maps can be designed to work with the same set of information resources, stored in any structured or unstructured format. Among potential uses of Topic Maps are: online navigational aids, virtual documents, filtering information for specific users and uses, and information structure support.

MAPS EXTENSIONS AND RELATED 3D VISUALISATIONS

A number of systems use some kind of Knowledge Map to support knowledge sharing and collaborative learning activities. Among these are:

- *Kmap*, a general Concept Mapping tool that supports collaborative learning through the World Wide Web [Gaines and Shaw, 1995];
- *KSE* (Knowledge Sharing Environment) which is a system of information agents for organising, summarising and sharing knowledge from a number of sources. In KSE, users are organised into user groups or communities of interest [Davies et al., 1998];
- *Semio solution* – a software technology for information categorisation and retrieval. It is based on constructing and developing a taxonomy based on lexical tools [Semio, 2001];

- *TheBrain* – a non-hierarchical knowledge management software producing a 3D visual map as shown in Figure 15. The software maintains relationships between issues in a dynamic manner, and URLs associated with a particular issue is displayed in a web-browser when the issue is made as the focus of attention. [TheBrain, 2001];

Figure 15: The *Mind Brain* software

- *MindManager* – an implementation of Mind Maps that allow the collaborative development of thoughts and ideas [MindManager, 2001];
- *WordNet* – an on-line lexical database developed on the basis of contemporary psycholinguistic theories of human lexical memory [WordNet, 2001];
- *ThinkMap* – a browser for exploring WordNet based thesaurus, using a Java-enabled spatial map, the Visual Thesaurus [ThinkMap, 2001];
- *Storyspace* – a tool designed for hypertext writers. Provides maps and views to help writers create, organise, and revise [Storyspace, 2001].

3.6 Final remarks

A number of technologies have been presented in order to inform about the development of a model to support collaborative learning by minimising cognitive overhead and information overload.

Among them are the World Wide Web, Information Retrieval and Virtual Reality, which provide different ways of organising information providing a number of useful ideas, and CSCW, CSCL, and CVE which highlight important collaborative issues that are needed to be present to support collaborative learning.

Additionally, visualisation and information visualisation offer a lot of potential for representing the structure of knowledge for sharing and integration with “real world” data. The chapter ends with the presentation of several strategies to represent and share knowledge.

The adoption of a virtual environment that embodies knowledge maps, 3D and collaboration facilities could have several advantages in supporting learning. An environment using a number of the described facilities could support both knowledge sharing and user understanding as presented in work reported in the current chapter.

Chapter 4 **– Graphical support for knowledge sharing**, presents a proposal for a system to share knowledge in collaborative learning, taking into account both the issues from chapter 2 (related with cognitive overhead, information overload and collaborative learning) and the insights resulting from the analysis of related work presented in this chapter.

4 Graphical support for knowledge sharing

4.1 Introduction

Following the thesis problem of how to share knowledge between a group of people, in particular people engaged in learning activities together, this chapter describes a system for knowledge sharing to support collaborative learning in a higher education context. It does that by taking advantage of the use of Huhns and Singh's proposal that users can contribute to enhance an existing domain knowledge model [Huhns and Singh, 1997]. Additionally, Huhns defends the idea of using a set of symbols to represent a knowledge domain to be used by each individual [Huhns and Stephens, 1999].

As introduced in chapter 3 – **From collaboration technologies to knowledge representation**, the use of a set of symbols in the visualisation design provides a visual mental map representation that can help to keep cognitive overhead and information overload problems minimal [Tufte, 1990].

In particular this proposal takes into account the need for minimising both cognitive overhead and information overload by:

- *cognitive overhead*: allowing an abstract high level for information representation [Norman, 1991] and thus providing the means to integrate data using Information Visualisation techniques [Card et al. 1999];
- *information overload*: allowing each individual user to take advantage of a structure for knowledge sharing and thus providing a context for reasoning about a particular knowledge theme [Huhns and Singh, 1997];

To inform about the work, an analysis of current issues regarding an environment to support knowledge has been discussed. In order to take advantage of how we use language and how it supports our construction of knowledge [Vygotsky, 1978], a structure for knowledge sharing has been devised based on words and its semantic relationships following ideas developed in the linguistics and semiotics fields [Schwartz, 1988; Hanf, 1971].

With these ideas combined with the construction of a textual structure based on meanings that can be built with the contributions of a group of people, it provides a basis for development of a common mental map as proposed by McAleese [McAleese, 1998]. Its value as an education tool as already been proved by Novak and Gowin and most of the times is used in conjunction with a graphical representation to ease how individuals understand and use it [Novak and Gowin, 1984; McAleese, 1998]. Collaborative learning is defined as groups working together for a common learning purpose [Resta, 1995]. To collaborate effectively in a group work, each individual must share a common grounding of concepts and be able to specify them in a form that allows individual reflection within the group. Each member of the group must possess a common mental map representation for reference, to understand the meanings and relations underlying a particular situation, topic, or subject knowledge. The common use of a visual representation of such a mental map allows for collaborative construction and enhancement, providing the opportunity to augment both individual and collaborative learning.

Additionally, some authors argue that efforts to improve learning and education must emphasise not only content but also context [Figueiredo, 2000]. In fact, Lewin and Grabbe state that learners play an active role in discovering knowledge for themselves and attest to the strong influence of the social environment of the learner in promoting changes [Lewin and Grabbe, 1945].

Also Vygotsky claims that knowledge results not from a transmission process but from the internalisation of social interactions [Vygotsky, 1978]. As stated by Damasio the use of visual representations can enhance the way individuals actually think and aid them in their efforts to share mental maps [Damasio, 1994]. New technologies that use 3D visualisation facilities and interactivity within virtual worlds seem to assist in minimising the difficulties by allowing abstract information, in the form of structured knowledge for representing contexts and meanings, to be visually mapped and explored using direct manipulation techniques. Such a representation can complement existing tools to allow context sharing of a given knowledge theme – a view of organising information about a particular knowledge theme. Thus, what is proposed is a visualisation to externalise a mental map in order to support its collaborative construction.

The proposed visualisation uses 3D facilities in order to allow both a natural world mapping and to deal with the high order of relationships that the concept network of the structure for knowledge sharing produce.

As one of the main characteristics of the structure that must be represented is its relationship network, the visualisation design must provide some cues to organise and orient users. The exploration of a 3D space for human interaction seems a natural option to do this. As Benedikt states, Cyberspace will provide a three-dimensional field of action and interaction: with recorded and live data, with machines, sensors, and with other people [Benedikt, 1991]. According to Wexelblat a well-structured view can make things obvious to the viewer and empower interaction [Wexelblat, 1991]. The view structure can convey an underlying mental model and can indicate possibilities for interaction in what Wexelblat proposes as semantic spaces.

The strategy followed for the visualisation design is to take advantage of collaboration between users to represent a domain knowledge so that it can be visualised and manipulated by each user for their own information needs and enable different data sources to be integrated with the structure for knowledge sharing.

The ViDESK name – *Visualisation Design for Sharing Knowledge* – results from its characteristics of using a 3D interactive visualisation to convey information about a structure for knowledge sharing. It provides a "visual desktop" to explore a view of a knowledge theme and allows both its sharing among a group of users and its enhancement. The control of the 3D interactive visualisation is made possible by using direct manipulation techniques. It provides a visual interface to explore, enhance and use the structure for knowledge sharing.

The rest of the chapter provides a detailed description of ideas used in the ViDESK proposal. The chapter is structured as follows:

- Section 4.2: – "An environment to support knowledge sharing", discusses the problem to be addressed and how it is currently solved. It also presents limitations and additional support needed in current solutions.
- Section 4.3: – "The proposal", discusses how additional support can be provided by presenting the basis for the proposed solution based on a structure for knowledge sharing and a visualisation design to convey information of the structure to support collaborative learning.
- Section 4.4: – "System functionality", presents an overview of the proposed system and its functionality concerning its use, the structure for knowledge sharing and the visualisation design to convey information about the structure.

- Section 4.5: – "Summary", provides a summary of the thesis proposal and what has been achieved. It also presents a brief description of what is to be covered in the next chapter.

4.2 An environment to support knowledge sharing

4.2.1 The problem

The problem to be addressed can be stated as the use of a shared structure for knowledge sharing, applied to collaborative learning tasks in a Higher Education context.

A definition of the term "knowledge" is required. The knowledge to be shared by the ViDESK system is provided by the structure for knowledge sharing. It provides a simple and understandable network of concepts, which eases individual participation in the building of a common structure, and thus, of the knowledge itself. It also describes the view of an expert or a group of users on a particular knowledge theme and provides the context to reason about a given domain or topic – tacit knowledge. Tacit knowledge is defined by Sveiby as the knowledge that is used as a tool to handle or improve what is in focus [Sveiby, 1994].

A more general definition of the term "knowledge" is given by Clare and Detore who describe knowledge as any form of active organised content [Clare and Detore, 2000]. These authors add that knowledge is a system made up of three elements: content – what the knowledge is about; structure – how the content is organised; and reasoning – defining dynamics of the system. The following discussion of sharing knowledge in a higher education context is based on this definition.

CONTEXT

Students may find it difficult to fully understand and put into context a given knowledge theme for which they need to construct their own structured mental model, in order to reason [Wurman, 1989].

As an example, for a computer science student learning about Human-Computer Interaction (HCI), a group of concepts about human factors are addressed along with more technical ones. The students need to have a clear mental model of the relationships between HCI, human factors and computers to understand, retrieve and use information about each topic given the general framework. If this knowledge does not provide a clear understanding for each of the concepts, the reasoning about the knowledge theme is, at least, limited. This limitation is more concerned with the knowledge that remains with the user after the learning process.

In general, any problem where information structure and complexity are important is a candidate for testing the ViDESK system for knowledge sharing. Other possible applications are Web Information Retrieval and Personal Information Management. Collaborative learning was chosen because it provides a feasible evaluation environment to test the system as a collective setting for knowledge sharing.

4.2.2 How the problem is currently solved

The traditional functions of the university remain almost the same since its origins. Universities are considered as the primary storehouses of information, the primary disseminators of information and necessary as communities of teachers, learners and researchers [Thomsen, 1999]. Current knowledge sharing in a higher education context is provided by lectures, seminars and lab sessions as the most traditional solutions [Puttnam, 1996 and Rossman, 1992].

- In lectures, an expert gives a structured perspective by introducing a particular knowledge theme and students take part normally as passive receptors of the information. One example can be a talk about Usability in HCI.
- In seminars, one or more experts give a group of integrated perspectives about a particular knowledge theme. One example can be a seminar in Usability theory and practices.
- Labs sessions allow each student to learn by doing, or experimenting on a given problem. One example is a lab session to test and evaluate the usability of a particular application interface.

To support lectures, seminars and labs, information for further student development is given as lists of readings, including papers, books and printed material and also as some multimedia material as video and CD-ROMS. In some cases hypertext-based material is also used, which is normally accessed on the web. This material serves as chunks of an information database that must be referenced.

Recent developments allow the use of Computer Supported Collaborative Learning (CSCL), Computer Supported Cooperative Work (CSCW) and also Web-based learning environments, but most of the times only to extend current knowledge sharing paradigms [Deden, 1998; Watters et al., 1998].

4.2.3 Limitations of existing solutions

The lecture, seminar and lab solutions, though valid for knowledge transmission, where one teacher engages in passing structured information to the students, have some limitations for knowledge sharing, where teacher and students are engaged in sharing their own opinions and difficulties. In particular, lectures, seminars and labs have a number of limitations:

- they provide a consumer model where each student receives information to form his/her own knowledge, and do not consider the student as a valid information producer. For example during a lecture, each student takes his/her own notes and does not usually describe his/her perspective about a particular lecture topic;
- information support usually relies on fostering information access, not facilitating student informed participation and empowerment [Arias, 1999]. For example during a seminar, a number of references may be given as topics for further reading, but no provisions are made to discover how relevant each student considers these references to be;
- they do not promote the collaborative organisation of common knowledge structures and the involvement of each of the students because of typical individual learning orientation. For example, assessment of students' knowledge is typically made through individual exams, which can be complemented, with other information such as, perhaps, group projects, but following an individual approach for assessment;
- the support for learning is based on a closed system from the student perspective because neither his/her notes become part of the available reading material nor are reflected in it. For example, some student notes address understanding problems related to concepts and links between different content. This can be made available to others but within current practices it is done on a non-integrated individual basis.

Also, approaches to educational systems based on well-tested conventional techniques have suffered from limitations that our system addresses in the following way:

- the complexity resulting from dealing with large amounts of unstructured information, and the difficulty of keeping pace with updating, verifying, and authoring information. This affects largely human computer interaction, and no novel solutions are in sight to solve this problem. In the ViDESK system, although the structure for knowledge sharing is stored in a textual form, it can be represented in a visual form. A visualisation design can improve the relation between a group of users and each user and the information sources that satisfy his/her information needs;
- the complexity of co-ordination between several information sources, when one tries to move to decentralised or distributed solutions, does not seem to be reduced as heterogeneity, and interoperability problems arise. Furthermore, the user interaction problem remains unsolved. In the ViDESK system, the use of a text-based structure for knowledge sharing eases use of available meta-data to search information sources, provided by existing Internet search engines and browsers. The proposed design of the visualisation structure for knowledge sharing addresses user interaction using direct manipulation techniques;
- the shift in information content from document referencing to context sharing does not seem to fit well with conventional available systems. Knowledge changes and evolves continuously and needs to be certified, authored, and represented in various formats and diverse applications. The proposed solution for knowledge sharing seeks to support a context by providing a higher abstraction level description that can be used both to support collaborative learning and data access by taking advantage of the structure for knowledge sharing.

ViDESK facilities are discussed later on in this chapter, in section 4.3, where the proposal is presented.

4.2.4 Alternative solutions

Other solutions that exist for sharing knowledge and supporting collaborative learning are Web-Based Learning Environments [Britain and Liber, 1999], CSCL and CSCW systems designed for collaborative learning [Lewis, 1999]. Although these solutions address the collaboration issues, they do not support an externalisation that provides a common model for knowledge sharing that can be collaboratively enhanced and used as a 3D interactive visualisation. Examples such as *FirstClass*, *WebCT*, *EFTWeb* and others are more concerned with providing an environment to allow collaboration than for knowledge sharing and its visual representation [Gouveia et al., 2000c].

A list of the limitations of existing collaborative learning prototype systems is reported in a Joint Information Systems Committee (JISC) report [Britain and Liber, 1999]. A list of the additional support needed in prototype collaborative learning systems is also reported in another JISC report [Kalawsky, 2000]. Existing efforts to represent meta-data and knowledge representations for easing information access related to educational settings are given, among others, by the IMS Learning Resource Meta-data Information Model [IMS, 2001], IEEE' LOM – Learning Object Meta-data [IEEE, 2001], the Dublin core [Weibel and Lagoze, 1997], ISO' MPEG-7 – Multimedia Content Description Interface [ISO, 2001], RDF – Resource Description Framework [Jenkins et al, 1999], and Topic Maps [Biezunski, 1999].

The ViDESK system proposes a different approach where the knowledge to be shared provides a context, which is one of the many possible views for the knowledge theme. The ViDESK system does not attempt to provide a unique definition for the knowledge theme being shared or even to classify content as most of the meta-data efforts do.

4.2.5 Additional support needed

Collaborative learning will allow each student to take advantage but also to contribute with his/her own effort to the group. This way, the consumer model where the student merely receives information can be transformed in a consumer/producer model, where the student also produces information to be shared among all.

Each individual needs to be involved in the knowledge construction and actively participate. As Clark and Schaefer claim, for knowledge co-construction to occur, participants must not only make a contribution, but must also get their contribution accepted by others [Clark and Schaefer, 1989]. This involves a notion of building something together by engaging each of the group members in a common activity – the enhancing of the structure for knowledge sharing. The notion of a common activity is central to collaborative learning where a group works together for a common purpose [Resta, 1995].

The evolution to a consumer/producer model can be an advantage because it can enhance knowledge sharing involving teacher and students. Constructing and structuring a network of concepts seems a good direction to enhance each student's perception of the knowledge theme, since each student's mental model, although an internal representation, can be represented as networks of concepts [Carley and Palmquist, 1992 and Jonassen, 1995].

Based on a similar approach, a structure that can support a network of concepts can be used and shared among students to provide a common structure as an external representation.

A network of concepts that represents the HCI theme gives one example of such a structure, where we can enumerate *Interface*, *Computer*, *User*, *Information*, *Data*, *Interaction*, *Usability*, among others. We can also list a number of characteristics for each concept and based on that, specify relationships among existing concepts. For example, *Usability*, *Interaction* and *User* can have in common a characteristic named *user*. A characteristic named *data* can be associated with *Computer*, *Information* and *Data* concepts. Note that we can have a concept and a characteristic with the same name. They are different because the concept is a list of characteristics and the characteristic itself can belong to any concept.

4.3 The proposal

4.3.1 The structure for knowledge sharing

The idea of using a structure for knowledge sharing comes from the use of concept maps and other knowledge representations already presented in chapter 3, section 3.5.2. A structure for knowledge sharing addresses the above limitations. It does that by proposing (with the teacher's involvement):

- the use of a structured concept description that can be enhanced by students (making them also producers), because of the implicit and explicit rules that such a structure represents, which in turn, when understood, facilitates the contribution of each individual;

- involving students in the co-construction of the structure (informed participation) and fostering the knowledge construction with as many group members as possible actively involved;
- use collaborative facilities to allow students' interaction with the structure by using a visual image that can be shared and modified, taking advantage of the way we thought, according to Damasio and providing a tangible externalisation for the knowledge been shared [Damasio, 1994];
- the use of a common structure can allow students' notes to be considered and integrated along with the knowledge sharing structure that evolves over the time (as an open system). This provides a means of supporting reuse and a growing corpus of related knowledge;
- provides a high-level abstraction structure to be used for integration with available information. Also, it provides a high level layer to support access to unstructured information (dealing with unstructured information). Due to its structured characteristics and textual form, it eases the creation of interfaces to integrate available information;
- as a text-based structure, it allows integration with current text search systems to seek content associated with groups of terms (concepts and its characteristics). This means that with some operations on the shared structure, ordered sets of terms can be generated to access a particular data source using a text search engine (heterogeneous and interoperability access information problems);
- by allowing sharing and collaboration, the structure can be enhanced and used to include new users' contributions (knowledge dynamic characteristics). This will provide the conditions to foster knowledge construction among the group members;
- because it is open to each student's contributions the structure can be enhanced and used more easily than other meta-data specifications that are bound to more formal rules (the IMS being an example), or context creators such as those provided by the Topic Maps standard [Biezunski, 1999]. In particular, it provides a possible link between data and context by not embedding context data but by specifying context independent representations.

HOW THE SUPPORT IS PROVIDED

To overcome the described limitations, we proposed a simple solution based on a high abstraction textual structure, keyword based, for discussion among users. The textual structure provides an easy way for supporting discussion among a group of people and takes advantage of the role of language in both thought and social interaction [Vygotsky, 1978]. These characteristics may turn the solution to a natural one, already known by individuals who use language as their main tool for knowledge sharing.

This structure provides a description for the knowledge to be shared thus providing a relation between each user's mental map and a collective description of a knowledge theme view, providing the creation of a shared context.

The proposed structure is composed of concepts and keywords. A keyword is any word that can be used to describe a particular characteristic of knowledge. A given keyword can be repeated as wanting to be included in different groups of keywords. Each keyword group represents a concept. The keywords associated to each concept have a rating that represents the degree of relation with the concept (similar to a fuzzy logic membership function).

Taking into account an example using a HCI context, we can propose a concept named *Interface*. The *Interface* concept can have several associated keywords as *computer*, *usability* and *user*. For each keyword we give a particular rating (a value between 0 and 1 that represents the degree of membership of the keyword in the concept): for example, 0.46 for *computer*, 0.80 to *usability*, and 0.67 to *human*. These values give an order of importance to the relation between the concept and each of the keywords – they are not probabilities, so their sum does not need to equal 1. These values are proposed and voted among group elements in order to specify an association degree between the concept and the keyword.

Later, the structure can be modified by adding and deleting concepts, adding and deleting keywords, and modifying existing keyword ratings, providing full flexibility to reorganise the context for a particular knowledge theme.

One example of a structure for knowledge sharing about the HCI theme can be composed of ten concepts as presented in Figure 16. These concepts result from an initial description that can be made by the teacher or from collaboration between users (teacher and students).

```
Computer: the information artefact “par excellence”
Data: the raw material to represent reality
Database: the technology to store and retrieve data
Enterprise: a group of people and resources organised to
meet a goal
Ergonomics: to deal with better systems to support human
operations
Information: the relevant data that support decision-
making
Interface: the mediation between computers and users
System: a ground concept of unity and utility
Technology: the tools that help humans
User: humans that operate (use) the technology
```

Figure 16: List of concepts and their meaning

Considering the ten concepts in the structure, many more can be added by any of the users, although, at first, users must propose keywords to describe each of these concepts. A possible resulting structure for the HCI theme is presented in Table 1.

Several keywords were added to each concept. For example, the *structure* keyword was added to the *System*, *Computer, Information*, *Database* and *Enterprise* concepts (highlighted in Table 1). Notice that the keywords used to describe the *Human* concept were included in the *Interface* concept. The values (between 0 and 1) placed with each keyword give the degree of relation (membership) between the keyword and the concept.

The structure is composed of the concepts, and for each concept there is a keyword set. The rating of each keyword also serves to establish an ordered list of importance for all the keywords belonging to the concept. A concept can be better described by including more keywords. The relation between two concepts is given by the existence of the same keywords even with different values associated. In the example, the keyword *structure* relates to (five concepts.

Notice that the resulting structure represents a mental map specification based upon the contribution of a group of individuals about the HCI theme. It provides a concept map for relating HCI concepts based on a common agreement between the group of people involved.

System **structure**, 0.24 order, 0.27 lifecycle, 0.45 component, 0.49	User human, 0.78 operation, 0.65	Interface order, 0.34 operation, 0.76 human, 0.8 computer, 0.56
Data operation, 0.5 data, 0.78	Information **structure**, 0.67 decision, 0.67 retrieval, 0.4 cost, 0.56	Database **structure**, 0.78 order, 0.7 data, 0.6 retrieval, 0.5 storage, 0.55
Computer order, 0.67 technology, 0.7 automatic, 0.67 processing, 0.8 **structure**, 0.7	Enterprise value, 0.56 technology, 0.44 **structure**, 0.24 system, 0.23	Technology lifecycle, 0.55 value, 0.78 operation, 0.68 change, 0.34
Ergonomics human, 0.7 lifecycle, 0.5 cost, 0.56		

Table 1: A partial structure for sharing knowledge about the HCI theme

Based on the same keywords and their values it is possible to obtain a value of similarity between two concepts. The keyword values from each concept are used in order to select which keywords are the most important for the context that deserve to be compared with the other concepts. For example, *User* and *Interface* have a strong relation based on the keywords *human* and *operation*. If we modify the value for the *human* keyword in *Interface* from 0.8 to 0.3, the relation between *User* and *Interface* is not as strong as before, although it still exists.

However, the relation between two concepts exists in cases where keywords are shared among them. Based on the structure, it is possible to establish the relationships between concepts of the knowledge theme being shared by the structure. Figure 17 lists the existing relationships for the concepts from the HCI related structure.

The simple use of concept, keywords and keyword ratings provide the means for a group of people engaged in the construction of a concept space expressing the knowledge being shared. It provides a simple but usable way to share knowledge between a group of people using language as the main tool, as claimed by Vygotsky [Vygotsky, 1978].

```
Computer: System (order, structure), Interface (order),
  Information (structure), Database (order, structure),
  Enterprise (structure)
Data: User (operation), Interface (operation), Database (data),
  Technology (operation)
Database: System (structure, order) Interface (order), Data
  (data), Information (structure, retrieval), Computer
  (structure, order) and Enterprise (structure)
Enterprise: System (structure), Information (structure),
  Database (structure), Computer (technology, structure) and
  Technology (value)
Ergonomics: System (lifecycle), User (human) Interface (human),
  Information (cost) and Technology (lifecycle)
Information: System (structure), Database (structure,
  retrieval), Computer (structure), Enterprise (structure) and
  Ergonomics (cost)
Interface: System (order) User (operation, human), Data
  (operation), Database (order), Computer (order), Technology
  (operation) and Ergonomics (human)
System: Interface (order), Information (structure), Database
  (structure, order), Computer (structure, order), Enterprise
  (structure), Technology (lifecycle) and Ergonomics (lifecycle)
Technology: System (lifecycle), User (operation), Interface
  (operation), Data (operation), Enterprise (value) and
  Ergonomics (lifecycle)
User: Interface (human, operation), Data (operation), Technology
  (operation) and Ergonomics (human)
```

Figure 17 Relationships between concepts

4.3.2 The visualisation design

From the textual structure it is difficult to detect the concept's relationships even with a small structure such as that considered above that has just ten concepts and 37 keywords. To ease user understanding of the structure, a better presentation must be provided.

An important issue is the structure of the visual representation. The solution offers a 3D interactive visualisation of the knowledge. The use of a visualisation design addresses the problems of minimising cognitive overhead and information overload, providing a virtual environment where the structure for knowledge sharing can be explored. As stated by several authors, spatial or visual representations appear to be easier to retain and manipulate than are textual representations [Arnheim, 1972; McKim, 1980].

As the structure must be collaboratively enhanced, a shared representation is needed. A study conducted of the construction of shared knowledge during collaborative learning suggests the importance of constructing a shared representation [Jeong and Chi, 1997].

The same authors stressed how critical, for a computer system, it is to provide an external representation in which participants can negotiate their own representation.

A number of graphical solutions for representing knowledge were available, such as those discussed in chapter 3, section 3.5.2. Most of these solutions use 2D graphical facilities that have been proved to be useful in learning contexts [McAleese, 1998]. However, considering our case and based on the complexity – that is to represent the structure for knowledge sharing relations even in a 2D representation –, we proposed the use of a 3D virtual world. This allows each user to explore the network of concepts, by moving around a planet-based metaphor.

The option for 3D is justified by the need to have a well structured view that can make things obvious to the viewer and empower interaction as defended by Wexelblat [Wexelblat, 1991]. The same author puts forward the concept of semantic spaces where we can convey an underlying mental model and indicate possibilities for interaction. Due to the high abstraction of the structure for knowledge sharing, a more human understandable approach is needed. This is the case of a 3D space where people can navigate and take advantage of a visualisation of a common mental map in a space with the same dimensions as in the real world. The potential of such virtual environments for collaborative learning has already been discussed [Kommers et al., 1996].

Along with a 3D interactive visualisation, additional direct manipulation facilities are included, adding a great sense of control to the user and promotes faster learning and higher retention [Shneiderman, 1998a].

Also, due to the abstract nature of a structure for knowledge sharing, an enhanced visualisation needs to be used in order to allow exploration as the one offered by the interaction with a virtual world. Thus, the structure for knowledge sharing uses a visualisation design to convey its information in order to facilitate its understanding and user interaction. The visualisation design helps to minimise both cognitive overhead and information overload.

The chosen structure externalisation also allows the integration of data source information taking advantage of a virtual world that can be explored; this virtual world allows the integration of the structure externalisation with other information sources, providing the means for context integration.

The visualisation design is based on the idea of a workspace where users interact by sharing a 3D interactive visualisation that allows direct manipulation and gives each user some control of the ongoing result. This control allows each user to participate in the changing of the structure for knowledge sharing, performing its analysis, and as a tool for integrating data source information within the context provided by the structure for knowledge sharing.

The proposed 3D interactive visualisation is based on a two-part visualisation design (Figure 18). The 3D interactive visualisation is composed of two parts, named *concept space* and *criteria space*.

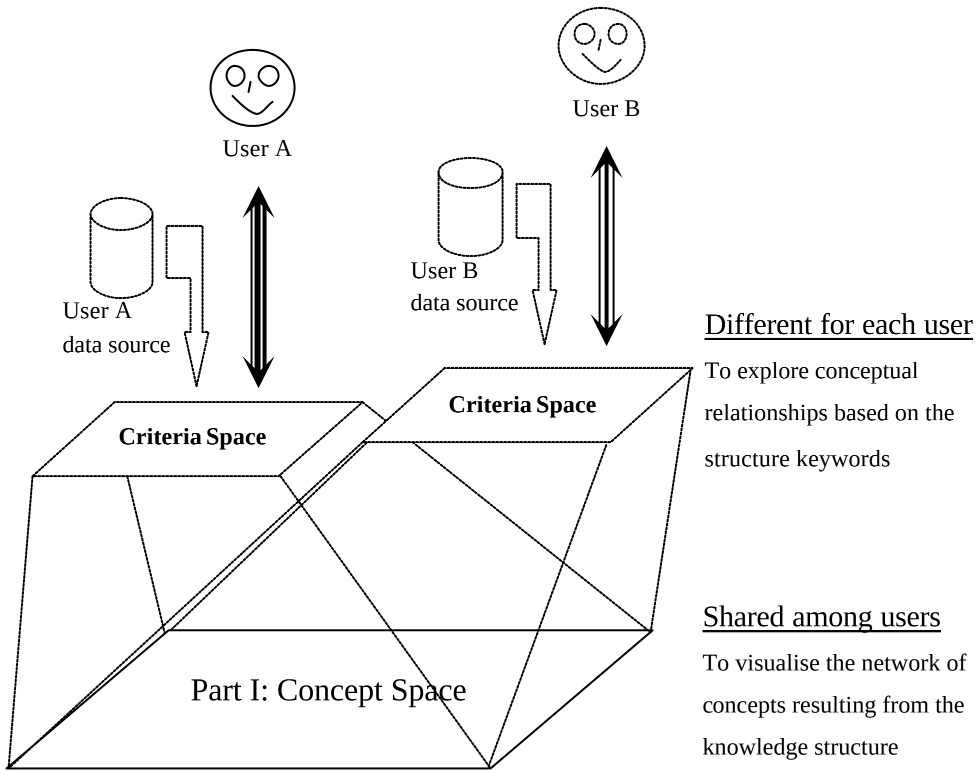

Figure 18: ViDESK two-part visualisation design

These two parts have different functionality and can be controlled independently by the user. We can summarise the role of each visualisation design part as follows:

- part I – *concept space* – provides a visual representation of the structure for knowledge sharing. As a network of concepts, the concept space is used as the interface to the structure that can be shared and edited collaboratively;
- part II: – *criteria space* – providing a visual representation of the structure for knowledge sharing that can be customised by the user, according to his/her particular needs. As the criteria space supports each user's needs, it is not shared

among users; it allows users to create their own criteria spaces and thus explore concept relationships based on the keywords. The criteria space includes an information visualisation facility for integrating data source information.

The two-part visualisation design allows both the sharing of the structure for knowledge sharing and its further exploration by each individual. The concept space provides a common view for all the group members that remains the same independent of each user navigating it individually. Any change to the concept space is the result of a collaborative exchange and impacts the concept space of all the individuals – this allows for the existence of a common mental map.

The criteria space enables each user to customise the visualisation allowing each individual to organise concepts according to their own criteria. Taking advantage of the structure for knowledge sharing, a second visualisation is built taking into account concept relations specified by each individual. The criteria space is oriented to the user's individual needs, providing a customised view of the structure for knowledge sharing. Each user can customise the criteria space as many times as he/she wants

Also, the use of a two-part visualisation design supports a solution for the problem of changes in the concept space visualisation. These changes may impact user orientation, if users were allowed to directly modify it. This problem, reported by several authors, occurs in some visualisation systems where the general appearance of the world changes with changes to its contents [Card et al., 1999].

The visualisation design addresses the problems of providing a common understandable base for sharing information [Tufte, 1990], and of taking advantage of the flexibility and ease of exploration of information spaces [Benedikt, 1991].

Concerning interaction with the information spaces, the use of a two-part visualisation design aids in solving the problem of spatial layout which reflects potentially dynamically changing information without the user's sense of position being affected by changes to the layout [Ingram and Benford, 1995].

THE CONCEPT SPACE

The concept space is used to support the sharing and collaborative enhancement of the structure, presenting the conceptual relationships. It also provides a global picture of the network of concepts to be shared among users and constitutes the image of the structure for knowledge sharing.

Each user interacts with the concept space to explore the structure for knowledge sharing. It is possible to discover existing relationships between concepts by using keywords as criteria for building a 3D interactive visualisation that represents these other relationships based on individual keywords: this is achieved by the criteria space, which supports users' individual information needs.

THE CRITERIA SPACE

The criteria space can also be integrated with a data source through an information visualisation. An embedded information visualisation facility provides support for analysing and comparing the data source with the context given by the structure for knowledge sharing. The information visualisation gives information about the data source content regarding similar groups of keywords (concepts) within it.
The criteria space is used to support users' individual exploration of the structure for knowledge sharing by identifying concepts that are associated with common keywords.

INTEGRATION OF THE CONCEPT AND CRITERIA SPACES

The integration of the two parts of the visualisation design results from both the concept space and criteria space use of the structure for knowledge sharing and as the information for rendering the visualisations. The main difference between the two visualisations is based on the spatial position rules used to place concepts.

In the concept space, the spatial position is part of the knowledge structure definition and cannot be modified by the user. The concept space is an open virtual space where each concept can be placed on any spatial position without restriction of range limits. Just one rule applies: each concept must be in a unique position not used by another concept.

For the criteria space, each user is able to influence a concept's spatial position by input, the criteria to be used for placing them (hence the name criteria space). The criteria space is also a defined virtual region where all the concepts must be placed in a range of available values. These values are related with the keyword values from the structure for knowledge sharing (ranging from zero to one).

4.3.3 Putting it all together

The proposed solution, combining the structure for knowledge sharing and the visualisation design for conveying structure information, provides the following support:

- all users are involved in the provision of a simple, easily understandable structure, based on keyword aggregations to describe concepts;
- a textual description of the conceptual relations means that each concept shares existing keywords with different membership degrees (ratings);
- a structure for knowledge sharing, available to all users, supports collaboration and context sharing;
- the collaborative enhancement of the structure of each user's participation in the structure modification (involving users in adding concepts, adding keywords, and altering existing keyword ratings);
- collaborative learning is supported in an environment where it is possible to share, enhance and explore information that provides a context description of a knowledge theme;
- cognitive overhead and information overload associated with large texts are reduced by the use of an interactive 3D visualisation to promote structure visualisation and exploration;
- techniques to compare the network of concepts with a data source allow the representation of information about the data source within the structure visualisation.

The 3D interactive visualisation provides a high level representation of the structure for knowledge sharing that can be used to support collaborative learning and to integrate information from a data source.

The ViDESK system provides the support for discussing and enhancing the structure for knowledge sharing. Also, the ViDESK system uses the structure for knowledge sharing to offer a knowledge theme as a context to reason and compare with content from a data source.

The problems associated with the sharing of knowledge between a group of people engaged in learning activities are addressed by ViDESK as follows:

- support for collaborative learning: collaborative learning is defined as groups working together with a common purpose, where individuals learn from being involved. The need for sharing a common ground of concepts is essential for maintaining each individual in communication within the group.
- minimisation of cognitive overhead: cognitive overhead results in a user becoming confused or having difficulties in making his/her choices and decisions. Cognitive overhead places heavy demands on the working memory.
- Minimisation of information overload: information overload means that the user has received more information than he/she can cope with. It occurs when the user's information processing capacity is exceeded.

4.4 System functionality

4.4.1 ViDESK facilities

Concerning the objectives of supporting collaborative learning, minimising cognitive overhead and minimising information overload, additional support is needed which is provided by the ViDESK system facilities.

A number of service facilities were considered taking into account the identifiable need, the system facility and how the ViDESK system implements it:

- NEED: the use of a structured concept description that can be enhanced by students (making them also producers)
  SYSTEM: allowing each student to add and delete concepts and keywords, and alter keyword ratings based on a voting scheme;
  HOW: any user can propose a modification of the structure (add a concept, add a keyword, and modify a keyword value). The voting result determines if the proposal is accepted or not.
- NEED: students involvement in the co-construction of the structure (informed participation)
  SYSTEM: supporting each user's interaction with the structure by exploration of the 3D interactive visualisation (concept space) and updating it each time the structure is modified. The 3D interactive visualisation (criteria space) supports

each user’s exploration of the keyword relationships. A two-part visualisation enables user exploration of the structure for sharing knowledge;

HOW: the two-part visualisation design allows a visual representation of the structure for knowledge sharing. The shared visualisation is the concept space – a network of concepts linked by their keyword similarity. The second visualisation – criteria space – allows user exploration of the concept space through spatial rearrangement of the concepts according to the user’s own information needs. The criteria can be any of the existing keywords.

- NEED: collaborative facilities to allow students’ interaction with the structure by using a virtual image that can be shared and modified.

  SYSTEM: support the use of a 3D interactive visualisation as a virtual world that can be explored and which conveys information about the structure for knowledge sharing;

  HOW: develop a 3D interactive visualisation to generate a virtual world that can be explored by users and implement the two part visualisation design, including user controls to access information of the structure for knowledge sharing.

- NEED: a common area to allow students’ notes to be shared and integrated along with the knowledge sharing structure. These common notes evolve over time with the students help (as an open system).

  SYSTEM: allows each student to submit related information to the network of concepts as Internet addresses (Uniform Resource Locators: URLs) and hints about the knowledge theme. This allows a common set of notes to evolve over time;

  HOW: using an annotation facility where each student's contributions are placed in a server for central storage and later retrieved by user request.

- NEED: a high-level abstraction structure to be used for integration with available data sources. A high level layer to support access to unstructured information.

  SYSTEM: the criteria space allows each user to take advantage of the structure for knowledge sharing. This provides the opportunity for informed data source access;

  HOW: The integration is made possible by using an information visualisation facility within the criteria space.

- NEED: to use the structure information with current text search systems to seek related content. Based on textual operations using the structure for knowledge sharing, ordered sets of terms (keywords) can be generated to access a particular data source using a text search engine (heterogeneity and interoperability information access problems).

  SYSTEM: the system takes advantage of the textual structure for knowledge sharing to extract search strings that can be used in search engines (both for the web or for use on a local disk or data base);

  HOW: The data access results are displayed using a standard browser. The search results are given by a Web search engine that allows the use of search strings and return results that can be displayed on a Web page.
- NEED: support discussion of the structure for knowledge sharing to promote its enhancement and allow user contributions (characteristics of dynamic knowledge).

  SYSTEM: a chat system for discussion among users;

  HOW: implement a chat system to allow users synchronous interaction in textual mode as a complement of the shared structure and its representation.

Table 2 summarises the ViDESK facilities that support collaborative learning by minimising cognitive overhead and information overload.

Limitations to collaborative learning and knowledge co-construction	Additional needs for collaborative learning support	How ViDESK can support the needs
a *consumer model* where a student merely receives information considered to be an information producer	using a structured concept description that can be enhanced by students allows students to be *producers*	allowing each student to add and delete concepts and keywords, and alter keyword ratings based on a ***voting tool***.
support usually *relies on fostering information access*, not facilitating student informed participation and empowerment	involving students in the co-construction of the structure (*informed participation*)	a ***two-part visualisation design*** to support structure exploration and modifications and to further explore concept relationships
no promotion of collaborative organisation of knowledge due to an individual learning orientation (*involvement of all students*)	use collaborative facilities to allow students' interaction with the structure by using a *visual image that can be shared and modified*	support the use of a ***3D interactive visualisation***, to be explored as the knowledge structure representation
support for learning is based on a *closed system* (from the student perspective) where annotations do not become part of the available material	use a common area to integrate students' notes with the evolving knowledge sharing structure (*as an open system*)	allow students to submit information as URLs and hints related to the structure. Provide an ***annotation facility*** to store and share information
complexity resulting from large amounts of unstructured information, and the difficulty of keeping pace with updates to it	offer a *high-level abstraction for integration with available information material*. Also, provide access to unstructured information	use the visualisation and structure as a context to support data access. This is possible by using an ***information visualisation***.
heterogeneity, and interoperability problems occur when one tries to move to decentralised or distributed ways of co-ordinating several information sources	the textual structure allows integration with current text search systems, allowing *ordered sets of terms to be generated to support data access*	extract search strings from the textual structure for knowledge sharing. Data access results are displayed (in Web search engine style) in a ***browser***
difficulty in shifting from information content to context knowledge - *Knowledge changes and evolves continuously*	by supporting sharing and collaboration, the structure can be enhanced and used to *support discussion*	this is an overall outcome of the system (structure plus visualisation) when used in complement with a ***chat system*** for users discussion

Table 2: Problems, needs and ViDESK support

4.4.2 ViDESK functions

The ViDESK (*Visual Design for Sharing Knowledge*) system can be described as supporting four functions, which allow it to be used as an interface for collaborative learning in a higher education context.

The functional perspective of ViDESK allows us to view the system as a knowledge sharing enabler and shows at a high level how it can be integrated with data sources. It also provides a high level view of its functions. The functions are (Figure 19):

- Collect: enhance the context provided by the structure for knowledge sharing by gathering user contributions;
- Provide: support knowledge sharing among users as a result of the interaction with the visualisation design, making it possible to organise and reason with a knowledge theme;

- Visualise: integrate information from a data source with the visualisation design allowing its comparison with the knowledge theme view;
- Produce: generates textual output about the knowledge theme from the structure for knowledge sharing. It allows the generation of search strings to support browse and search activities.

The ViDESK system is based on the assumption that the structure for knowledge sharing and the visualisation design can support user interaction, where each user takes advantage of the system to share, explore, discuss a given knowledge theme and analyse data source information regarding the context provided.

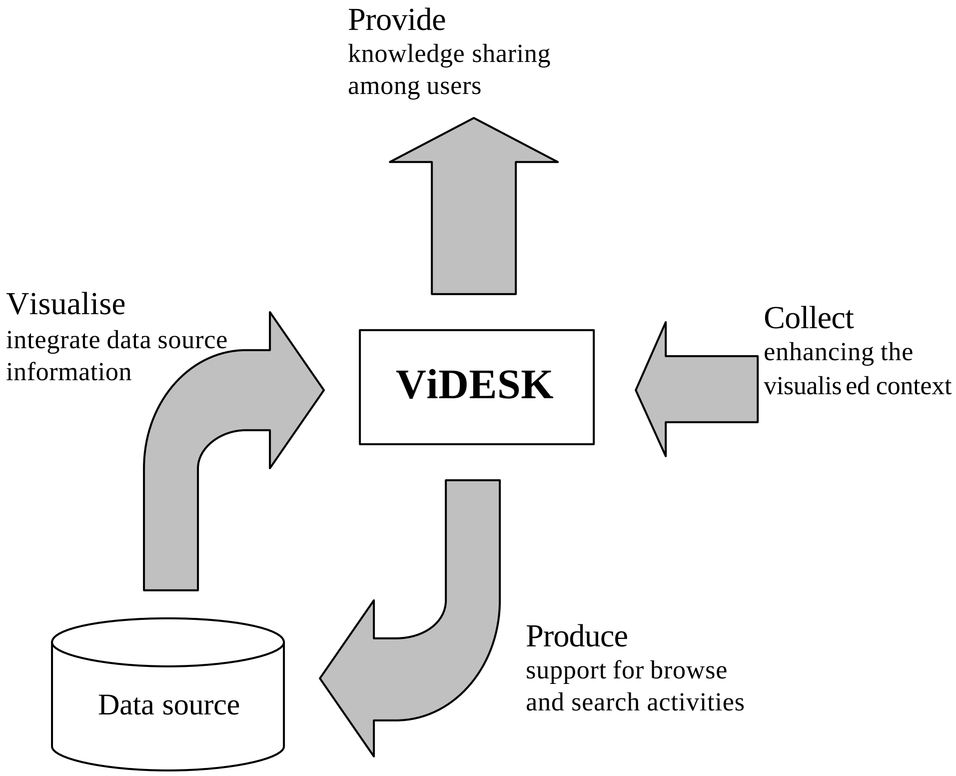

Figure 19: The four functions of the ViDESK system

Figure 18 and Figure 19 contain information on how the ViDESK visualisation design integrates with a data source. Each user can take advantage of sharing the structure but he/she has his/her own possibilities of using the structure information to individual exploration and to take advantage of the data source integration facilities.

The ViDESK functions PRODUCE and VISUALISE are related to the user. The other two ViDESK functions – PROVIDE and COLLECT: – are related to the group. These four functions provide a view of ViDESK functionality and emphasise how the structure for knowledge sharing and the visualisation design can be integrated with data sources containing *"real world"* data.

4.5 Summary

Based on the problem of how to share knowledge between a group of people engaged in learning activities, a structure for knowledge sharing was proposed. It provides a structured way for specifying a common mental map to be used by a group for collaborative learning.

In order to allow the use of such a structure for knowledge sharing, a visualisation design was proposed to convey information of the shared knowledge structure. In order to inform ViDESK ideas, a number of studies were followed concerning interface, learning and information issues (chapter 2) and the use of graphical knowledge representations (chapter 3).

The system was designed to address the problem of sharing knowledge among a group of users, in particular students and teachers in a higher education context. The goal is to support knowledge sharing for collaborative learning by minimising cognitive overhead and minimising information overload.

This is made possible by taking advantage of the use of a visualisation design to present and allow exploring information about the structure for knowledge sharing. The ViDESK system offers support for:

- interaction between users, by taking advantage of a two part visualisation design;
- exploration of a network of concepts representing knowledge sharing – context – by taking advantage of the visualisation design as an interface;
- analysis of the structure for knowledge sharing based on concept relationships by providing a 3D interactive visualisation – concept space;
- analysis of the structure for knowledge sharing based on concept keyword relationships by providing a second 3D interactive visualisation – criteria space;
- comparison and analysis of the knowledge theme – context – with information from a data source by providing an information visualisation within the criteria space;

- create search and browse activities by providing a string search generation facility to be used in textual search engines.

The next chapter 5 – **A model for a visualisation for knowledge sharing**, presents the ViDESK model and discusses the design options taken to provide the support for collaborative learning using such a virtual environment. It extends the proposal chapter by providing a description of how the system has been proposed as a visualisation design for sharing knowledge and provides a virtual environment for collaborative learning support.

5 A model for a visualisation for knowledge sharing

5.1 Introduction

Chapter 4 – **Graphical support for knowledge sharing**, presents a proposal allowing the sharing of knowledge among a group of people engaged in learning activities together, to support collaborative learning.

In particular, a system is proposed for sharing knowledge based on the use of a 3D interactive visualisation to convey information about the knowledge being shared. In order to represent and organise such knowledge, a structure was built to specify a knowledge theme, which is viewed as a structured concept network composed of concepts, keywords, and keyword ratings as introduced in chapter 4.

Additionally, the model for a Visualisation Design for Sharing Knowledge was developed to take into account the need for minimising cognitive overhead and information overload [Wurman, 1989]:

- to minimise cognitive overhead support must be provided to allow user understanding, confidence and feedback regarding his/her choices and decisions;
- to minimise information overload support must be provided to leverage the amount of information available to the user by providing representation facilities and customised detail.

Considering the proposed visualisation design for representing the structure for knowledge sharing, a number of requirements can be enumerated.

- *ease collaborative learning* by providing a visualisation design to convey the structure for knowledge sharing.
- *address the problem of cognitive overhead*: by exploring the visualisation design, the user can exploit the structure for knowledge sharing as a space, allowing a more simple and user friendly alternative for structure presentation than text.
- *address the problem of information overload*: the visualisation deals better with the information overload problem both by using a reduced set of symbols and through the visualisation. A visual representation is provided for the conceptual relationships. The interaction with the visualisation allows information spatial

rearrangement to highlight concept relations, fostering the structure for knowledge sharing exploration.

Figure 18, from chapter 4, presents the proposed two-part visualisation design, which features two visualisations: the concept space visualisation and the criteria space visualisation.

The **concept space** visualisation, while allowing each student to explore conceptual relationships and the content of the structure for knowledge sharing, does not allow the repositioning or regrouping of concepts. This is because, the concept space is a shared visualisation, and so any modification impacts the group as a whole and may lead to confusion.

Support must be considered for each student to further explore existing relations in the structure for knowledge sharing. This support is provided in an independent way and without interfering in the concept space visualisation using the two-part visualisation design. It thus provides a second visualisation to allow each student to further explore concept relations based on their keyword description.

In the **criteria space** visualisation, each student can create and modify independently from other students, as it is not shared. The criteria space visualisation allows the association of concepts based on their keywords and according to the needs of a particular student. The criteria space is based on assigning to each of the three axes, keywords that allow for the repositioning of the concepts based on having or not the corresponding keywords. This allows regrouping and repositioning concepts according to a set of criteria input by each student. As the criteria space is associated with each student, he/she can alter it as desired and without interfering with the shared concept space. For example, having a context about *Information Management*, a useful view for a student could be a criteria space that relates concepts by using keywords such as *cost*, *information* and *management*. The resulting criteria space visualisation provides a different focus of the network of concepts with each of them grouped according to these specified keywords.

This way, the system for sharing knowledge offers a common representation for the network of concepts and the flexibility to further explore and generate new visualisations – any number of criteria space visualisations – based on the structure for knowledge sharing.

The two visualisations (concept space and criteria space visualisation) use the same structure for knowledge sharing, providing different and complementary views.
This chapter presents the model of the ViDESK – *Visualisation Design for Sharing Knowledge*. It follows the proposal presented in chapter 4, and extends it by introducing the associated concepts and visualisation design in detail. ViDESK allows the sharing of knowledge using a structure for knowledge sharing and provides a virtual environment for collaborative learning.

A number of ideas were adopted from current literature to inform about the visualisation design. In particular, these concerned the use of colours and the use of few information elements [Tufte, 1990], the way the system presents its symbols and allows user interaction [Benedikt, 1991], and the interaction between users and how they can benefit from this [Wexelblat, 1991].

Although the above ideas were followed, no attempt was made to study the interface and perform comparative studies to choose the visual elements and metaphors other than the used planet-based metaphor that was actually used. A planet-based metaphor seems to be a good metaphor to describe mental maps [Damasio, 1994], and extending semantic maps [Kalawsky, 2000]. Additional facilities such as chat and voting systems are also considered in order to foster collaboration and take advantage of the existence of a common mental map representation.

The chapter is structured as follows:

- Section 5.2 – "The structure for knowledge sharing", introduces the structure and its associated definitions.
- Section 5.3 – "The visualisation design", presents the model for creating a two-part visualisation design to convey information and allow the exploration of the structure for knowledge sharing.
- Section 5.4 – "ViDESK integration with data sources", discusses how ViDESK integrates information about the structure for knowledge sharing with information from a data source. It also presents the use of the structure for knowledge sharing to generate textual output to support data source queries.

- Section 5.5 – "Sharing issues", discusses the networked services that ViDESK must have to support the sharing and collaborative enhancing of the structure for knowledge sharing.
- Section 5.6 – "Summary", presents a summary of the ViDESK model. Additionally it briefly introduces the next chapters.

5.2 The structure for knowledge sharing

5.2.1 Definitions

The structure for knowledge sharing allows a user to specify a particular knowledge theme. The structure has been designed to be shared, and collaboratively enhanced by a group of students and teachers in a higher education context.

We can cluster information based on agreed keywords about a problem, describe a knowledge area, or build a given context. To structure the collected information, the keywords are grouped together, based on their role in a relevant topic within the context. The reasoning over and the justification for the structure was given in chapter 4, section 4.3.1.

The use of a structure based on concepts and associated words can be thought of as a network of concepts with an associated meaning as defended by several authors [Vygostsky, 1978 and Clark, 1996].

A knowledge theme results from using the structure for knowledge sharing. It provides a context to reason about a given knowledge area, described by using the structure for knowledge sharing.

The structure for knowledge sharing is composed of three elements, named as structure elements:

- concept – C,
- keyword –K,
- keyword rating – R.

Based on these three elements it is possible to built a network of concepts and specify a knowledge theme to be shared. The structure for knowledge sharing can be stated as a set of concepts. Each concept is a set of keywords. Each keyword has a corresponding rating value (Figure 20).

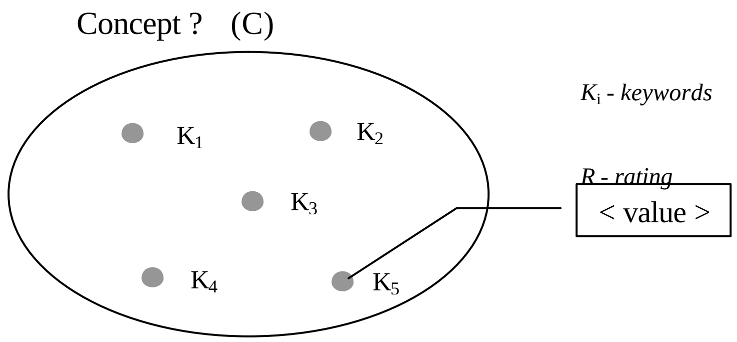

Figure 20: Concept, keyword, and keyword rating

- The *concept* is identified by a name of the concept or object it represents. Any number of keywords characterise a concept.
- A *keyword* identifies a particular characteristic that can be associated with a concept. A keyword is identified by a name of the characteristic or property it represents.
- The *keyword rating* is always associated with a keyword. It defines the degree of membership of the keyword with the concept. A numeric value between zero and one provides the degree of membership, with up to two decimal places.

One concept example is *User*. To be defined, it must be considered within a given context as, for example, *Information Visualisation*. This concept can be composed of any number of keywords; let's give just four in this case with the corresponding ratings: *human* with a rating of *1.0, user* with a rating of *0.76*, *value* with a rating of *0.6*, and *operation* with a rating of *0.4*. Note that the keyword *user* does not need to have a rating of *1.0* as its association with the concept *User* could have any rating value.

The keyword *human* with a rating of (1.0) is strongly associated with the concept *User*. Also, the *user* keyword is associated with the *User* concept. The same concept is also related to *value* and *operation*, the *value* association being stronger (0.6) than the *operation* rating (0.4).

A *concept* also has a *type*; the concept's type is used to provide additional information about the importance of the concept within the network of concepts.
Based on the need to classify the concepts by their importance regarding the context, a three level classification was chosen because it is simple, and easy to learn and apply. Sachter suggests the need for a simple and easy way to use classification when classifying concepts, regarding it as an important issue considering how learners

construct sophisticated mental models in a 3D space [Sachter, 1991]. The three concept types defined are:

- *critical* –a concept that must be present to the definition of the context provided by the structure for knowledge sharing. It is considered the most important type level;
- *base* – constitutes the basic concept to complement information given by critical concepts. It is the usual type of concept to be included in the structure for knowledge sharing;
- *normal* – a concept that helps the description of a context provided by the structure for knowledge sharing, although it may be considered as a less important concept or subsidiary concept considering the knowledge theme – context – being described.

Examples of the use of concept types, considering an *Information Management* context are:

- *Information* as a critical concept, being the main resource to be considered in Information Management, it may be seen as one of the key concepts in such a context;
- *Database* as base, because although it refers to an important concept within the Information Management context, it is not among the most critical ones;
- *Work* as normal, because it is neither a critical concept nor a base concept, it still deserves to be included as taking part in the structure for knowledge sharing.

A keyword can be used by different concepts with different associated ratings. If a particular keyword exists for two concepts, this means that both concepts share the characteristic described by the keyword. This is a way of relating concepts.

A knowledge theme specifies a context using the three structure elements. The possibility of repeating the same keywords with equal or different keyword ratings in more than one concept allows the creation of a network of concepts, which can contain complex relationships among defined concepts.

The process by which keywords and concepts are fed into the system is based on the contribution that each user can make to the overall context definition (provided by the structure for knowledge sharing). Each user can participate in the structure enhancement by proposing new concepts, new keywords, and altering the ratings of existing keywords.

5.3 The Visualisation Design

5.3.1 Introduction

In order to convey information about the structure for knowledge sharing, a two-part visualisation design is proposed as discussed in chapter 4.

3D facilities could foster understanding, exploration and discovery [Card et al., 1999]. This can be of interest when considering people engaged in learning activities. User task oriented situations favours the use of a virtual environment, one example is the sharing and enhancing of the structure for knowledge sharing. The use of 3D facilities provides a richer environment and allows the co-existence of information representations with integration and interaction facilities, as proposed by ViDESK ideas. The use of such a 3D space also deals with complexity by providing means for understanding, exploration and discovery within a virtual environment regarding its size and number of objects.

The 3D interactive visualisations are presented in the following sections: the concept space visualisation (section 5.3.2) and the criteria space visualisation (section 5.3.3), both based on the structure for knowledge sharing.

5.3.2 The Concept Space visualisation

The first part of the proposed two-part visualisation design is the concept space visualisation. This 3D interactive visualisation provides a visualisation to be shared as the common representation for the structure for knowledge sharing.

One of the main goals of this visualisation is to provide a visual network of concepts for a shared mental map. This way, each concept's spatial position must remain constant despite any changes to the structure for knowledge sharing. Spatial positioning has an important role in allowing users to recognise and identify parts of the network of concepts.

To deal with changes in the network of concepts and yet be able to represent the concept relationships (justifying the name of network) aspects of proximity must be represented.

This proximity, based on each pair of related keywords and taking into account their ratings, is based on computed semantic distance value and is explicitly represented using a symbol to connect the two concepts.

The concept space visualisation offers a network of concepts that provides a visual representation of the structure for knowledge sharing but allows the spatial positioning of each concept to remain the same. They are the explicitly represented relations that can change, modifying the shape of the network of concepts.

The spatial position of each sphere is provided once and becomes part of the information conveyed by the structure for knowledge sharing. The spatial positioning is regarded simply as user input to facilitate the referencing in the network of concepts or to provide some particular visual arrangement for the concept space visualisation.

CONCEPT SPACE DEFINITIONS

In order to obtain a visualisation of the network of concepts that conveys information from the structure for knowledge sharing, the following must be carried out:

- represent all the concepts specified in the structure for knowledge sharing;
- provide an indicator of how each concept is composed in terms of keywords and associated ratings. This is important because regardless of the concept importance for the given context, some clue must be provided as to how the concept is characterised by keywords and corresponding keyword ratings. Thus, by taking into account the number of concept-associated keywords and their ratings it is possible to provide a measure of how this concept is described in the structure for knowledge sharing. This measure is the concept description rate that can have a value between zero and two.
- provide an indicator of the importance that each concept may have in the context of a particular structure for knowledge sharing. This is given by concept type as introduced in section 5.2.1 as a structure for knowledge sharing definition;
- represent the existing relations between concepts to visualise the network of concepts. The relations between each two concepts are analysed taking into account the description of each of the concepts and how they relate to each other. This gives a metric for comparing the keywords and their ratings, considering the relative importance of each of the concepts, and selecting the

most important keywords in the two concepts for comparison. This similarity measure is called semantic distance, calculated as a function of keyword similarity between two concepts [Foo et al., 1992; Baeza-Yates and Ribeiro-Neto, 1999]. The semantic distance is a number between zero and one. If the value is zero, this means that there are no common keywords and no relation can be made between the two concepts. If the value is one, this means that most of the keywords are the same on the two concepts or that one of the concepts has many of the keywords of the other concept.

Figure 21 provides a representation of the graphical objects in the concept space visualisation. The used components in the 3D space are spheres; lines between spheres, corresponding labels and, in the origin point of the 3D space (given by null co-ordinates for X, Y and Z), a small axis representation, for orientation.

The user can navigate among the collection of concept space elements, exploring the structure for knowledge sharing and analysing existing conceptual relations.

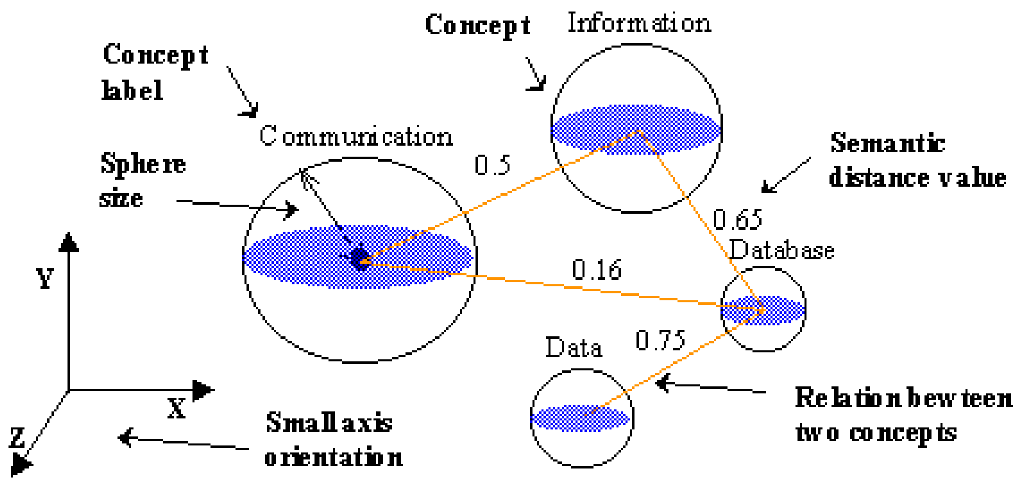

Figure 21: Elements in the concept space visualisation

In order to give meaning to the different symbols used in Figure 21 the following correspondence is made with the structure for knowledge sharing elements (*concept*, *keyword*, and *keyword rating*):

- each *sphere* represents a concept;
- the sphere *size* is related with the keywords and keyword ratings that describe each concept. The sphere size is given by the *concept description rate*; The use of the sphere *size* as a representation of the *concept description rate* in the

concept space visualisation was selected because it provides an associated indicator. It is known that the use of size in virtual environments is not very effective [Ingram and Benford, 1995]. However, in the case of the concept space visualisation, it does the job of providing a clue to be confirmed by the user with other interaction facilities. More importantly, it makes the concept space visualisation less monotonous because not all spheres have the same size.

- each *line* represents the *semantic distance* between two concepts;

Each *sphere* has a label that is the name of the concept in the structure. Each line has a label that is a value between zero and one, corresponding to the *semantic distance*. The spheres' spatial positioning has no meaning; they are placed arbitrarily.

The justification for using spheres and lines is given as follows. A number of alternatives were considered for representing the concept:

- use of text: There is a limitation on using intrinsic dimensions on text [Benedikt, 1991]. It also requires a more restricted perspective to read the text, and a need to be close. But the most important issue here is the need to have a mental map representation which is more associated with visuals to take advantage of the way we externalise ideas and represent them [Damasio, 1994 and Hutchins, 1995]. The use of text requires from users an additional effort because we are used to reading text and not seeing it as graphical;
- use of a restricted collection of symbols. This solution also has some problems regarding the need to map those symbols to some sort of concept classification, which is against ViDESK ideas of dealing with abstract information. We must remember that the structure for knowledge sharing can be applied to any context, describing a particular view of a given knowledge theme. Also, this solution requires learning to take place and mismatches may occur;
- use of solid shapes. This solution is interesting because it provides the visual clues, independent from the text. It also provides a higher number of possibilities for using intrinsic dimensions to represent additional information. From the most basic solid shapes as sphere, cube, cylinder and others, the chosen one was the sphere. The sphere has no sides and looks exactly the same from each perspective. Thus it provides a visual clue to the network of concepts without adding extra complexity.

The use of the line to represent semantic distance was chosen as the most simple solution, as it can support colour, be labelled and its goal is simply to relate (link) two concepts. Considering that each concept's spatial positioning remains the same since its creation, a visual clue must be used to indicate the evolving concept relations, based on the modifications of the structure for knowledge sharing.

Other alternatives to represent the semantic distance could be the use of solid shapes, but those do not add anything more to the current solution. An alternative option could be the use of a dynamically neighbour's formation as proposed by a number of systems [Card et al., 1999]. This solution may confuse users regarding a stable mental map presentation that must retain the same appearance regarding perspective and user exploration.

To render the concept space visualisation two additional issues must be considered: the use of colour for rendering the spheres and the lines. Colour allows us to define additional intrinsic dimensions [Benedikt, 1991] for use in the concept space visualisation. The use of colour also helps to provide the notion of a 3D space [Tufte, 1990].

Colour also has a similar effect as that described for sphere size. It helps to make the visualisation interesting and aids user recognition of particular regions in the visualisation (non-monotonous) [Benedikt, 1991].

A colour-coding scheme is used for the spheres, indicating the concept type. Three different colours are considered:

- *red* is used to represent critical concepts;
- *blue* is used to represent base concepts;
- *light blue* is used to represent normal concepts.

A similar colour-coding scheme is used for the lines, providing a visual clue about the level of the existing semantic distance value. Four levels are considered indicating levels of relationship between concepts, corresponding values of *semantic distance* and colour used:

- strong relation: a value between (0.75) and (1.00), represented as *red*;
- upper medium relation: a value between (0.5) and (0.749), as *blue*;
- lower medium relation: a value between (0.25) and (0.49), as *light blue*;

- small relation: a value between (0.0) and (0.24), as *white.*

By default, only the *red* and *blue* lines are shown in the concept space visualisation. The user can control whether or not the others are displayed.

CONCEPT SPACE EXAMPLE

The concept space visualisation is a 3D representation of the structure for knowledge sharing as a network of concepts. In the concept space it is possible to navigate around existing concepts (*spheres*), visualise their types (sphere *colour*), relations (*coloured lines*), and assess each concept collection of keywords (sphere *size*).

Figure 22 presents a concept space visualisation example, where four spheres (concepts) with different sizes (collection of keywords) and two lines (semantic distances) are represented. Some of the spheres are linked together which indicate the presence of common keywords and semantic distances.

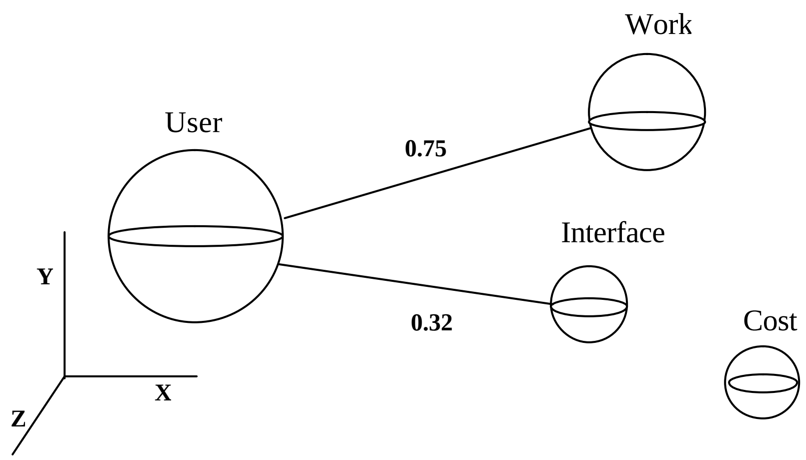

Figure 22: A concept space example

One of the spheres is isolated – the *Cost* concept – without lines linked to it. This means that its keyword group is not currently related to others. However, it must be pointed out that, for computing the semantic distance, only keywords with higher keyword ratings are considered. This means that even a concept with a small semantic distance value can have keywords that exist also in other concepts.

The *User* and *Work* concepts are closely related as indicated by the (0.75) value for the semantic distance. The relation between the *User* concept and *Interface* has a smaller value (0.32) for semantic distance. This indicates that a more closed relation can be expected from the *User* concept with *Work*.

The axis visualised at the origin point of the 3D space serves as an orientation support. With the X-axis vertical, it is possible to read the labels on the concept space visualisation. This is a reference position for orientation, allowing a user to situate his/her concept space exploration.

SPATIAL POSITIONING IN THE CONCEPT SPACE

The spatial positioning of each concept is specified by the information available in the concept object from the structure internal representation. These co-ordinates work as do the external ones, referred to as the extrinsic dimensions [Benedikt, 1991]. These co-ordinates are responsible for mapping the concept space elements into a 3D space in a way that is common for all users and remains constant for each concept from its creation onwards.

Concepts are placed in the visualisation not by any degree of semantic proximity between concepts but according to the result of voting polls. Although this may be seen as a drawback, since the spatial position cannot be used as a semantic clue, it provides support for user navigation by identifying relative positions of existing concepts that remain constant even when the structure for knowledge sharing has been modified. This principle has been proposed in other works as reported by Chen [Chen, 1999].

For rendering the concept space visualisation, each sphere needs to be placed in the 3D world in a unique position. Additionally, spheres should not overlap with other visualisation components. A method for sphere positioning is based on having a defined grid where each sphere can be placed. Once calculated, the 3D co-ordinate values remain constant for each concept in the structure. Figure 23 shows a method for generating valid 3D co-ordinates for use in the concept space visualisation.

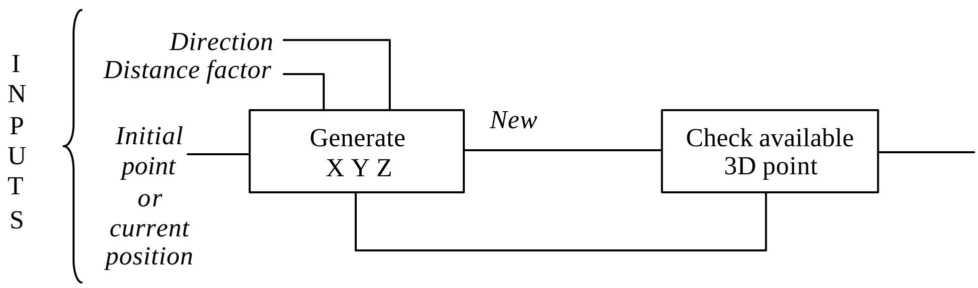

Figure 23: Block diagram to generate valid 3D co-ordinates

The user can choose a possible *direction* to place the new sphere, from a number of alternatives. The direction indicates the relative position from a 3D point from which to place a 3D object. Considering a 2D space it is possible to specify 9 distinct positions, including the origin. This number results from combining three options for each dimension – positive, negative, and null values. Following the same scheme but considering a 3D space, with positive, negative and null values for each dimension, it is possible to identify 27 different sequences corresponding to available directions, including the current position or starting point.

The *distance factor* is constant and the chosen value is (2). This particular value has been chosen to allow existing spheres not to intersect with the new sphere. The distance factor can be changed as a parameter for the minimum distance between two adjacent spheres. The distance factor value provides a way of tuning the dimension of the sphere's placing grid defining the distances between each position of the grid, used to place a sphere.

To render the spheres in the concept space visualisation, the algorithm must gather information from the concept object and use *concept description rate* for the sphere size. Also, the colour coding for the sphere is performed, using the concept *type*. The colour coding scheme for the *lines* and the decision for its rendering is based on the *semantic distance* value, computed for each pair of concepts in the structure for knowledge sharing.

5.3.3 The criteria space visualisation

The second part of the proposed two-part visualisation design is the criteria space. It allows the user to organise the visualisation of the network of concepts according to a group of criteria. The input criteria enables the individual user to explore the structure.

The 3D interactive visualisation provides to each user a visualisation to complement the concept space visualisation and further explore the structure for knowledge sharing. The criteria space visually represents conceptual relationships based on keywords, not concepts, as is the case for the concept space visualisation.

The criteria space visualisation offers the opportunity to use an alternative spatial positioning for visualising the structure for knowledge sharing. It is integrated with the concept space visualisation as it uses the same structure for knowledge sharing but represents it in a different way.

The main difference between the visualisations is on the organising of the available structure information. The criteria space visualisation enable user's to represent inputted criteria. These criteria can be any of the existing keywords of the structure for knowledge sharing.

CRITERIA SPACE DEFINITIONS

Three characteristics define the criteria space visualisation. They are the *3D space organisation* and the notions of *criteria* and *octant*. The *3D space organisation* explores the 3D characteristic to take advantage of assigning a particular variable to each dimension and create a 3D space to visualise concepts organised according to these variables. If any of the keywords allocated to each dimension are changed, the visualisation changes accordingly. It is thus possible to create as many different visualisations as the sequences used for the three available dimensions, provided by the available keywords from the structure for knowledge sharing.

A *criteria* specifies the relation between each variable dimension and its relation with the structure for knowledge sharing that must be used. Such criteria related with the structure are concept keywords. The keywords are used because they have a label with associated meaning and a value (the keyword rating) that provides a numeric value to be used for rendering the 3D visualisation.

The criteria space visualisation allows the relating of concepts from the structure for knowledge sharing by specifying existing keywords belonging to one or more concepts. Thus, the visualised relationships come from the keyword groups of each concept.
As the main goal of the criteria space visualisation is to group concepts according to their keyword ratings, and using the keywords as the criteria, the notion of *octant* is introduced. There is a need to divide the criteria space into regions to help with concept grouping.

The use of the three dimensions supports eight possible *octants* resulting from and considering the sequences of positive and negative values for each of the dimensions in the 3D space as presented in Figure 24.

For example, all the concepts that have in their keyword group the keywords used for a criteria belong to the first *octant* where all the criteria values are positive. The opposite happens for the *octant* where all the criteria values are negative, which means that the concepts placed there have none of the keywords used as dimensions for the criteria space visualisation.

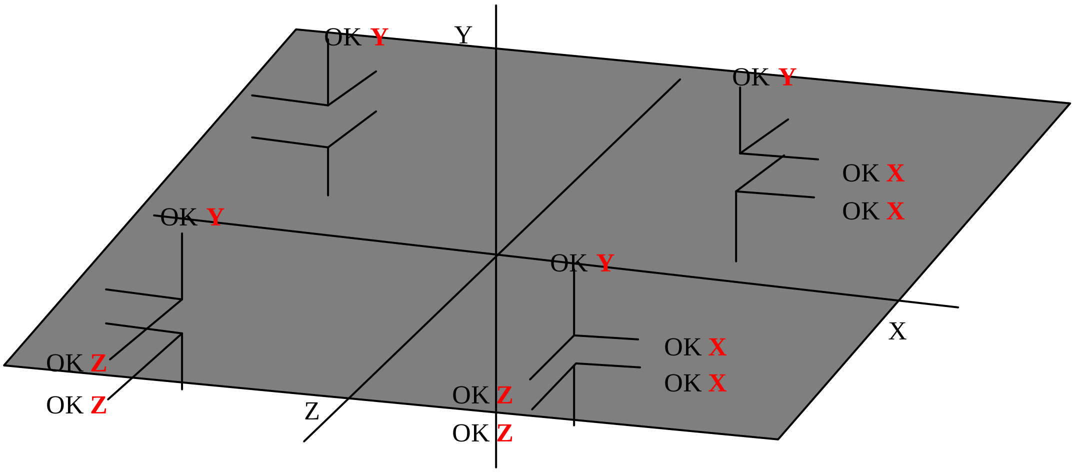

Figure 24: Octants in the criteria space visualisation

Another distinction between the criteria space and the concept space visualisation is that within the criteria space, the range of possible positions for any concept are only those allowed within the axis limit. The criteria space visualisation works as a 3D-space graphic, taking advantage of being a 3D interactive visualisation to allow different perspectives to explore it.

The criteria space visualisation allows for the regrouping of available concepts based on particular keywords. As the criteria space is created individually by each user and is not shared, it provides a tool to further explore the structure for knowledge sharing according to each user's individual needs.

Figure 25 presents a partial example of a possible criteria space visualisation with four concepts represented. Each one has the concept name associated to the corresponding sphere as a label. The axes have keyword names as labels since existing keywords from the structure for knowledge sharing can be used as valid criteria. The placing of each sphere is the result of the corresponding keyword rating to each of the three dimensions. All the spheres have the same size, which means different sphere sizes are an effect of the viewing perspective of the 3D criteria space visualisation.

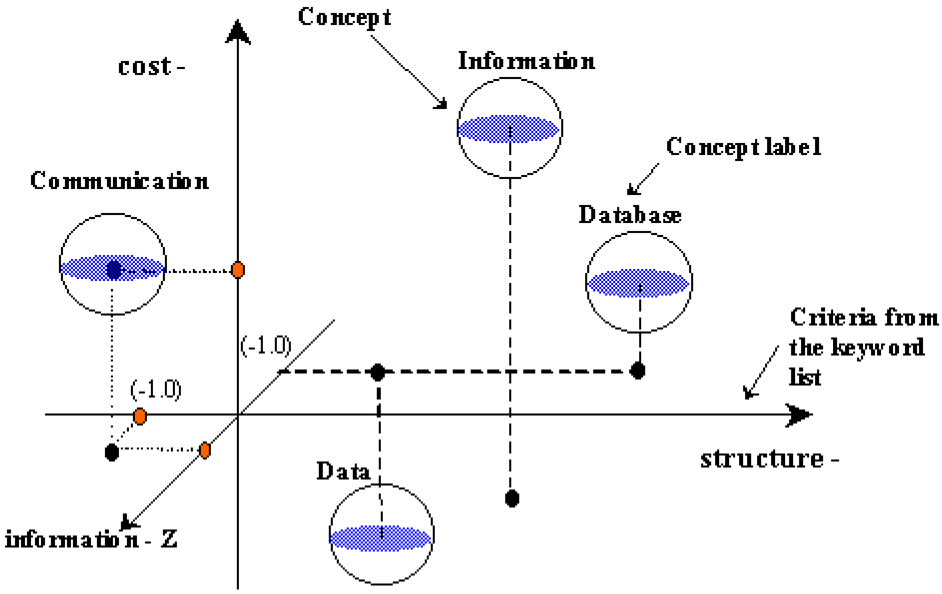

Figure 25: Elements in the criteria space visualisation

The criteria space visualisation differs from the concept space visualisation in the way it organises the same basic concept symbol and conveys information from the structure for knowledge sharing. The criteria space visualisation does not use:

- *lines* between spheres. This means that no semantic distance between concepts are represented;
- sphere *size* as an indication of the concept group of keywords. This means that no provision is made for representing the concept description rate. The effect is that all the concepts are represented by spheres of the same size;
- the concept spatial positioning provided by the concept object. Instead, the concept's spatial positioning is based on inputted criteria. This will be discussed further in the next section.

Although all the spheres in the criteria space have the same size they still use the colour coding for the concept *type* specified in concept space visualisation. The chosen sphere size value takes into consideration the need to minimise concept’s superposing in the visualisation, since sphere’s positioning in the criteria space is given by concepts’ keyword ratings.

CRITERIA SPACE EXAMPLE

The criteria space visualisation gives a 3D interactive visualisation that supports organising concepts from the structure for knowledge sharing according to user-entered criteria. The concepts (spheres) are organised according to three axes (orthogonal lines in the visualisation) that provide the rules of each of the user entered criteria.
Just for demonstrating the perspective, includes in the plane formed by X-Z axis (associated with the *value* and *process* criteria), the projection point for each sphere's centre. The points and projection lines are not part of the visualisation.

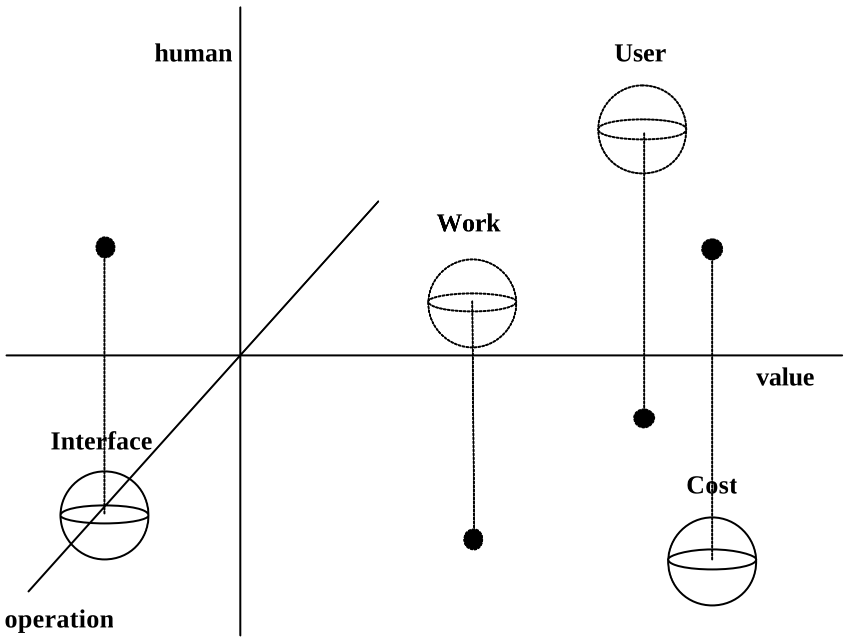

Figure 26: A criteria space example

Figure 26 presents a criteria space visualisation, where four spheres (concepts) with the same size, and the axis are represented. The sphere sizes are equal but as they are not in the same plane, the more distant spheres seem smaller. The represented concepts are *Work*, *User*, *Cost* and *Interface*. The axes are labelled with their assigned criteria: the *value* keyword for X, the *human* keyword for Y, and the *operation* keyword for Z-axis.

In this example just the concepts *Work* and *User* have met all the three criteria met. This means that for these concepts, the criteria exist as keywords in their keyword group. It is possible to compare the concepts by examining the concepts' spatial positioning. The *Work* concept has the greater rating concerning the *operation* criteria. The *User* concept has greater rating in the other two criteria: *value* and *human*. Note that the *Cost* concept does not meet any of the *human* and *process* criteria but has the greatest rating among the four concepts, regarding the *value* criteria. The *Interface* concept does not meet any of the criteria.

This way, it is possible to customise the criteria space by entering different criteria and thus forming different alternative visualisations. The concept representations – spheres – are positioned to each other in ways that vary as resulting from the use of different criteria. This supports analysis of how particular criteria may influence the concepts grouping. For example, considering the same concept as in Figure 26, but using as criteria *decision, value* and *human* instead of *value, human* and *operation,* we get the following criteria space visualisation (Figure 27).

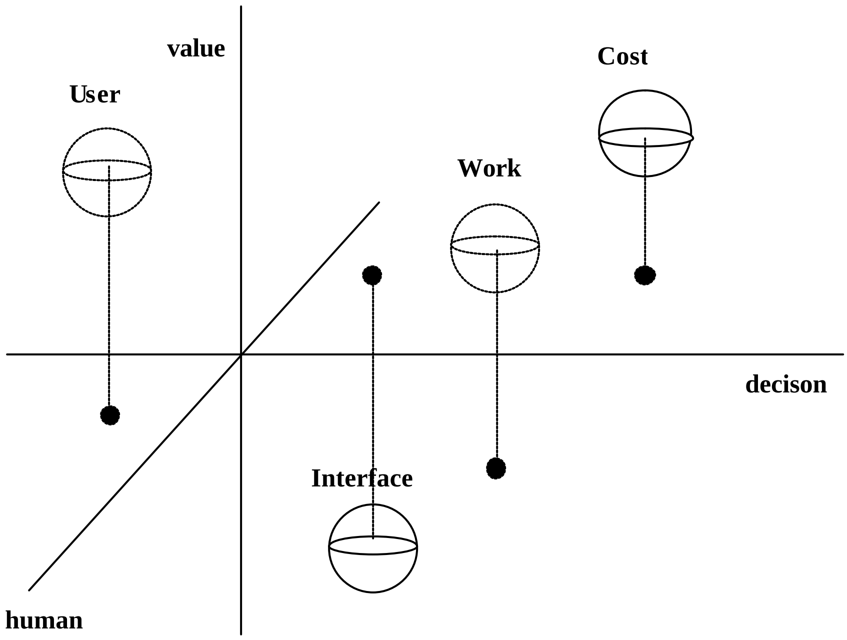

Figure 27: Another criteria space example based on the same concepts

This time, the concepts are placed in different positions, showing their relation with each other, based on a different criteria space. For example, this second criteria space visualisation shows that concerning the *decision* criteria, the concepts *User* and *Work* are no longer together as in the case of the previous criteria space visualisation.

Overall, the concepts are placed in the criteria space visualisation in one of eight different *octants,* according to how much they meet each of the defined criteria as specified in Figure 24.

SPATIAL POSITIONING IN THE CRITERIA SPACE

Concerning the spatial positioning, each sphere is placed according to the existence of a matching keyword with the criteria, using the keyword rating as a value. Provisions must be made when a given concept does not have the keyword used as criteria. This means that the corresponding keyword rating cannot be considered as a value of (0.0) because it has not been specified. Some rules concerning the concepts positioning are needed.

For each axis, there is a positive value, which gives the corresponding keyword ratings, and a negative value for placing the concepts that do not have the corresponding keyword. For those concepts, the negative value is always the same, a value (-1) for the corresponding dimension. Figure 28 describes dimension co-ordinate assignment.

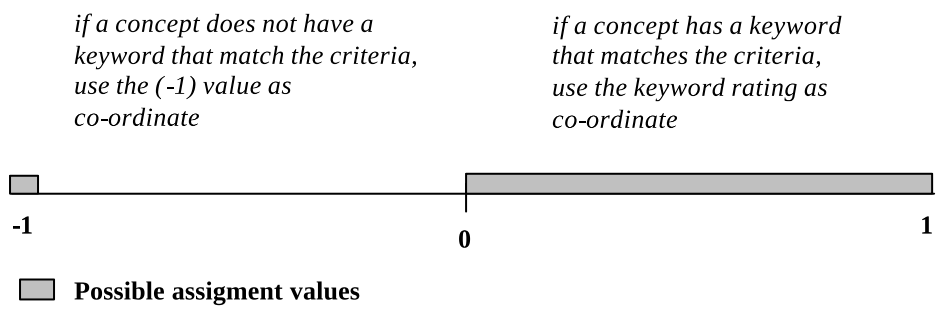

Figure 28: Spatial positioning reasoning for the criteria space visualisation

5.4 ViDESK integration with data sources

5.4.1 Introduction

As one example of ViDESK potential for integration with existing systems, the proposed visualisation design for sharing knowledge can have some level of integration with data sources. Examples of data sources are SQL compatible databases and Web search engines such as Altavista (*www.altavista.com*) and Yahoo (*www.yahoo.com*). With a Web like search engine interface, a hard disk can be used as a data source in the ViDESK context.

When considering the use of the ViDESK system one problem is how to integrate it with available data sources. This means dealing with how to pass from a high-level description of a knowledge theme to a database that represents data. The knowledge theme is represented by the structure for knowledge sharing.

Some alternative approaches can be followed to integrate the ViDESK system with data sources:

- *manually*: by adding structure keywords to each content occurrence in a data source. This is not feasible for large data sets and is context dependent;
- *use an interface to the database*: by providing filters to translate the structure elements from the structure for knowledge sharing to available information in the data source. This solution is feasible but it is also context dependent;
- *initial set-up of keywords* as the result of a particular database schema. This way, the structure for knowledge sharing in the ViDESK system is controlled by forcing structure elements to have some degree of matching with the data source. This solution is against the ViDESK aim of being a visualisation for sharing knowledge. Also, this solution is context dependent;

The previous alternative approaches are all context dependent. This means that for each knowledge theme view, procedures related with these approaches need to be repeated. Clearly, an approach is needed that provides content independence. This means the need is for integration with a data source without having to perform any special procedures each time a new knowledge theme is created.

The approach of *no need to tag or classify* the data source is followed because the main goal of ViDESK is to provide a visualisation design for the sharing of knowledge. The ViDESK system can take advantage of the structure for knowledge sharing to produce textual output, which, in turn, can be used for data source integration.

This allows ViDESK to produce information for use with the data source. To allow the integration of information from a data source, the ViDESK model proposes the use of an information visualisation. An information visualisation is a visual presentation of information spaces and structures to facilitate their rapid assimilation and understanding [Andrews, 1997]. Information visualisation can be defined as the use of interactive visual representations of abstract, non-physically based data to amplify cognition [Card et al., 1999].

Figure 29 shows how a data source is integrated with ViDESK. This integration is made by taking advantage of the criteria space characteristics, allowing data source information to be integrated with it, by using an information visualisation.

The ViDESK system produces textual output from the structure for knowledge sharing taking advantage of the structure elements to generate search strings. These search strings can be used with any data source that accepts a textual search interface. The search results are displayed using a Web style browser.

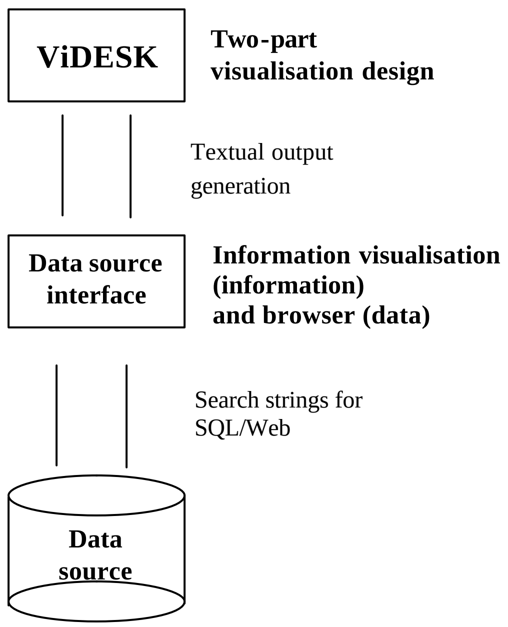

Figure 29: Map ViDESK with data sources

From the perspective of the data source integration, the ViDESK system can be seen as an information discovery tool which allows the co-existence of a knowledge theme – context – with a data source – content – by using visualisation techniques to convey structure information and data source information together. Section 5.4.2 describes the ViDESK information visualisation and section 5.4.3 introduces the textual output generation facilities.

5.4.2 The information visualisation design

The proposed information visualisation allows integrating within ViDESK, information about data source content. This information is represented as visual elements that can be compared with visual elements from the visualisation design. Thus, information from the structure for knowledge sharing can be put together with information from a data source.

The information visualisation is integrated with the criteria space visualisation. The criteria space visualisation is the individual user's visualisation and the one that can be generated by entering three criteria to form a 3D space. The information visualisation is associated with the first octant of the criteria space visualisation, where all the criteria are satisfied.

The two information visualisation visual elements are a *cylinder* and a *line*. The *cylinder* is used to represent a concept equivalent to the data source and has a label on top of it with the number of occurrences in the data source. The cylinder is a common symbol to represent a data source, being used to take advantage of its direct and specialised use as suggested by Tufte [Tufte, 1990]. All represented cylinders have the same size as their concept symbol counterpart, regardless of the number of occurrences that they may represent. Also, all cylinders have the same colour: green.

The placing of the data source element – *cylinder* – has an associated meaning. It uses the same rules that apply to the spatial positioning of concepts in criteria space. The data source criteria ratings are calculated counting the number of occurrences associated with each keyword, giving the total number of occurrences for all the keywords that belong to the concept.

The line is used to link the cylinder to the associated sphere, indicating the concept to which the data source information is related. Also, the sphere and cylinder's relative positions provide an indication to how information from the structure for knowledge sharing and data source content may differ, based on keywords used as criteria for this criteria space.

Figure 30 presents the visual elements for the information visualisation, integrated within the first octant of the criteria space visualisation with its visual elements already presented in Figure 25.

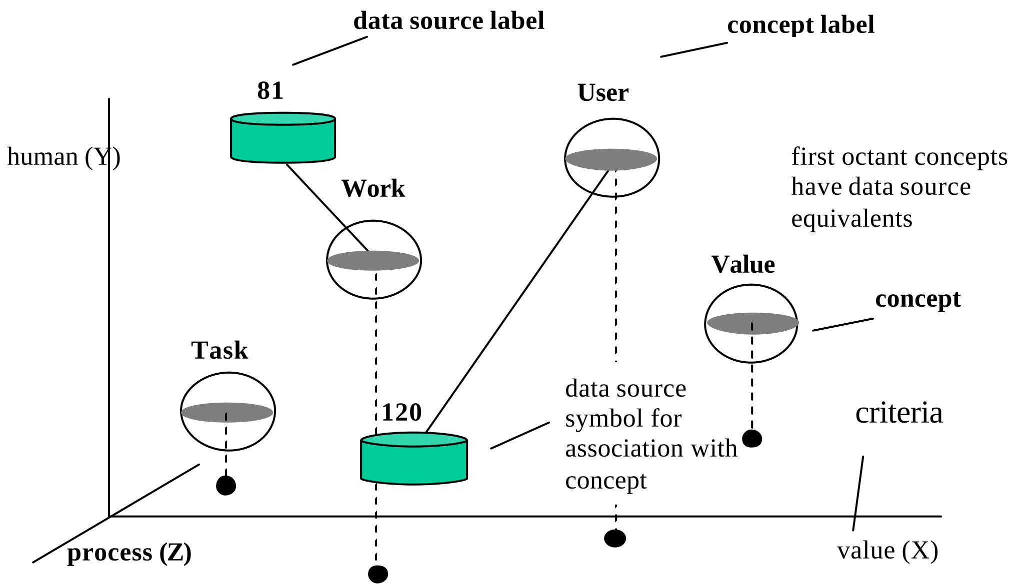

Figure 30: Elements in the information visualisation

In Figure 30, only two of the four represented concepts are in the first octant. For these concepts in the first octant, according to the criteria space defined by the X, Y and Z criteria, the corresponding data source indicates that there are some differences between the information provided by the knowledge theme and its data source equivalent.

These differences are more visible in the Y criteria (human) and for the X criteria (value), where the data source symbols have smaller values when compared to their concept counterparts. This may indicate that the data source is not the most appropriate to find information about the two concepts given the X, Y, and Z criteria within the given knowledge theme. The use of ViDESK textual output generation and a browser to display data source entries will help in supporting these indications.

The idea behind having an information visualisation within the criteria visualisation is based on the work of Huhns and others, who propose a structure similar to the structure for knowledge sharing as a context to mediate data access [Huhns and Singh, 1997; Huhns and Stephens, 1999]. The value of the proposed information visualisation can be summarised as follows:

- provides a semantic indicator of how the selected concepts match their data source counterparts;

- provides a string search generation facility about a given context, to support information retrieval.

5.4.3 Textual output generation

The ViDESK system produces textual output from the structure for knowledge sharing to be used with data sources. The textual output allows the composition of queries related to the knowledge theme being shared.

The use of the structure elements to compose query strings support querying a data source and integrating a high-level context description of a knowledge theme, exploiting the particular context to inform the access of a data source.

SEARCH STRING GENERATION

The ViDESK system provides two types of queries: *concept* and *keyword*. They differ in the way they use elements from the structure for knowledge sharing to form the query.

The *concept* search type uses the keywords that belong to a concept to form the query. The concept keywords are used to compose a string with all keywords belonging to a concept, ordered by higher keyword rating. The *concept* search can be useful to retrieve information related to the concept, when performing a textual search in a data source. For example, for the *User* concept, with keywords *human, user, operation*, and *value*, the output search string presents the keywords with spaces between them: "*operation value user human*".

The *keyword* search type uses keywords with higher keyword ratings from all the concepts in which the target keyword exists. The final list of keywords is ordered by keyword ratings and the keywords with higher scores are selected. The *keyword* search composes a query based on related keywords from the context in which some relation can be established with the input keyword.

For example, consider the concepts and their keywords: *User* (*human, user, operation, value*); *Work* (*human, operation, value, decision, experience*) and *Value* (*experience, value, information*). Performing a keyword search using the *operation* keyword related the *User* and the *Work* concepts creating a joint list of keywords: "*human operation* *value user decision experience*", this being the exact order of the keywords given by the sum of ratings considering the corresponding keyword ratings in the two concepts.

BROWSE DATA SOURCE RESULTS

Using the two types of queries to a data source, the result is displayed as a list of hits, referencing data source entries. The list of results is displayed using a Web style browser that uses a link for each of the result entries to display information or provide access to it.

The ViDESK system uses a Web style browser for displaying data source results. For integration, the browser command needs to receive as input a URL (*Uniform Resource Locator*) including the search string.

One example can be the following string for the concept search for *User* using *Altavista Search Personal Extension* on a local machine:
http://127.0.0.1:6688/?pg=q&what=0&fmt=.&q=+%2Boperation+%2Bvalue+%2Buser+%2Bhuman.

5.5 Sharing issues

Information about users and the structure for knowledge sharing support is provided by a network service. The user information has been minimised on the current ViDESK implementation and was composed of a name, a student number, a password and a small description given by the user him/herself. The ViDESK system supports user information and maintains the structure using a server. The server is responsible for providing a common structure for knowledge sharing to all users and maintains updated information about structure changes every time they occur.

Additionally, a number of services must be present to support ViDESK functionality:

- *voting system*; to enable users to elect which enhancements to the structure are accepted. Valid contributions are new concept, new keyword, altering an existing keyword rating. The voting process is based on one vote for each user. The options for voting are three: yes, no and neutral. The proposal is accepted in cases of 50% or more "yes" votes.

- *chat system*, which supports user exchange of textual information in real time, to support discussion. The chat system identifies each user by his/her login name and all the discussion text is echoed for all users - no private channels are allowed.
- *annotation system*, where related information such as hints and URLs about each of the concepts in the structure for knowledge sharing can be placed. The annotation system stores each user contribution with the user's name and date of contribution. The contributions are organised by concept and are accessed by each user from an annotation server using the concept space visualisation as an interface.

These services can be considered as complement services to the ViDESK model in order to allow the use of existing applications. The voting, chat and annotation systems can be integrated with ViDESK or operate as independent services as long as it is possible to have information transferred between services, described for each of the services as follows:

For the *voting system*:

- input: the description of the proposal to be considered in the vote contained user name, type of proposal and its elements. The proposal elements are the associated concept and keyword object fields from the structure for knowledge sharing internal representation;
- output: the voting result, being one of the three options: yes, no and neutral. This output will be used to decide if the structure is updated with the user contribution.

For the *chat system* no data needs to be transferred to ViDESK. The service can work independently once it supports real time discussion.

The *annotation system*:

- input: this service needs the user name, referenced concept, a hint about the knowledge theme or a URL submitted for inclusion in the annotation database. Other input concerns requesting for information about a particular concept on giving its name;
- output: database content for the corresponding concept.

5.6 Summary

The model for the ViDESK system has been presented. Both the structure for knowledge sharing and the visualisation design were described as the main core of the model. In particular, a planet-based metaphor was used and a two-part visualisation design followed.

The ViDESK design options were justified in order to inform the creation of a visualisation design for sharing knowledge in a virtual environment for collaborative learning, following the proposal presented in chapter 4. A reduced set of symbols has been presented in the form of spheres and lines along with colour, size and spatial positioning. Additionally, a cylinder symbol has also been proposed for use in the visualisation design.

The structure for knowledge sharing and its elements has been specified, being a structured list of concepts and for each concept, a list of related keywords and keyword ratings. Special attention has been given to visualisation elements and how they map onto the structure for knowledge sharing.

Additionally, a number of issues regarding the ViDESK model have been covered in order to discuss how the system integrates with data sources and how it supports sharing. In particular, a context independent approach has been selected to take full advantage of ViDESK characteristics.

The work is focused on demonstrating the use of a 3D interactive visualisation to convey information about a structure for knowledge sharing to support collaborative learning by minimising cognitive overhead and information overload. The proposed system can be used as a mental map representation for building and enhancing knowledge between users and thus support collaborative learning. Based on student collaboration, a visual representation of the structure for knowledge sharing allows all the students to share a concept space visualisation as a network of concepts using a planet-based metaphor.

Chapter 6 – **Implementing a knowledge sharing system**, provides a detailed description of the ViDESK implementation, including a number of the ViDESK prototype screenshots and its implemented functionality.

Chapter 7 – **Experiments to evaluate the system in use**, reports how ViDESK has been evaluated, and what needs to be evaluated, and chapter 8 – **Experimental Results**, reports data gathering and its analysis following the specifications for the ViDESK experimentation.

6 Implementing a knowledge sharing system

6.1 Introduction

Chapter 5 – **A model for a visualisation for sharing knowledge,** provides the specification to develop a system for knowledge sharing in support of collaborative learning, ViDESK (*Visualisation Design for Sharing Knowledge*). It describes a 3D interactive visualisation, composed of two parts: a concept space and a criteria space. These visualisations are generated using a structure for knowledge sharing and provide a representation for the knowledge theme to be shared.

This chapter describes the implementation of the ViDESK system. The prototype has been developed to investigate the use of a structure for knowledge sharing and a visualisation design to convey information about a knowledge theme. The aim is to support knowledge sharing for collaborative learning by minimising cognitive overhead and information overload.

This chapter also describes the use of ViDESK in actual sessions. Results of pilot testing are also discussed. The chapter is structured as follows:

- Section 6.2: – "Prototype platform and architecture", describes the architecture of the system and the implementation decisions.
- Section 6.3: – "Using the prototype", describes the implemented ViDESK prototype. It introduces the use and operation of the ViDESK prototype version that was used in the evaluation phase.
- Section 6.4: – "User scenario", provides a description of a group of people using the ViDESK prototype to discuss and enhance a structure for knowledge sharing.
- Section 6.5: – "Summary", summarises the chapter content and briefly introduces the next chapters.

6.2 Prototype platform and architecture

6.2.1 Prototype platform

The ViDESK prototype was developed for testing purposes, namely the empirical study as will be described in chapter 7 – **Experiments to evaluate the system in use**. In particular, the prototype was developed to test how systems such as ViDESK help to minimise cognitive overhead and information overload and support both individual and collaborative learning. The implementation is based on the ViDESK model presented in chapter 5.

The ViDESK prototype was designed to run in standalone mode or in a TCP/IP network. The network mode requires the use of the ViDESK server and the ViDESK clients for the users in the group.

The ViDESK prototype was developed using a Windows 95 box with the ViDESK server running in the Windows NT operating system. The implementation language is Java with the following specifications:

- Sun JDK (Java Development Kit) for Windows 32 bits, version 1.2.2;
- Sun Java 3D JDK extension for OPEN GL for Windows 32 bits, 1.1.1;

In particular, a number of Java techniques and features have been used in the ViDESK prototype development, i.e. Collections, Serialization, and input/output for prototype logs and to store and manipulate user and shared objects. For the graphical interface both AWT and SWING have been used. Network support used Java networking, threads and RMI. In addition to the Sun documentation other documentation was used [Eckel, 1997; Flanagan, 1997; Farley, 1998; Brown and Petersen, 1999]. The prototype development time was about ten months for programming and testing. Minor corrections were made.

6.2.2 Prototype architecture

The system is based on a client/server architecture to support the sharing of the structure for knowledge sharing. Figure 31 describes the implementation architecture.

In the ViDESK server side, two persistent objects (representing the users and the knowledge structure) are maintained as well as the proposal and voting system, a chat system and the structure sharing service.

On the client side, the ViDESK client allows each user to explore a two-part visualisation design. This visualisation design is composed of a concept space visualisation representing the structure for knowledge sharing and the criteria space visualisation, which allows rendering of a 3D visualisation to fulfil user needs. The criteria space visualisation allows integration of data source information with the structure for knowledge sharing.

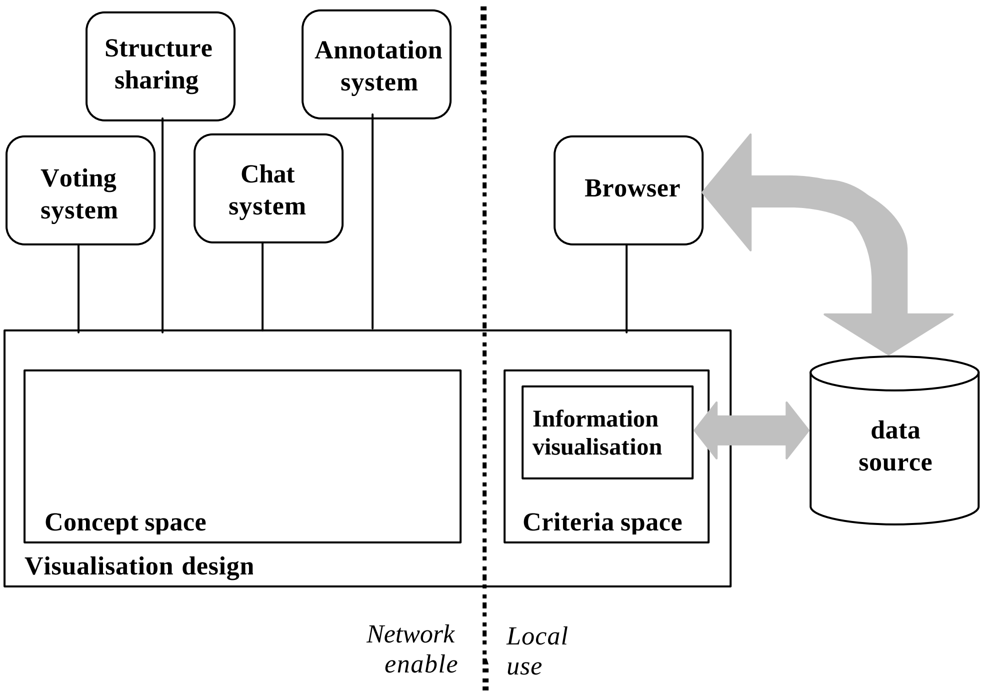

Figure 31: ViDESK prototype architecture

The current version of the ViDESK prototype implements the visualisation design and integrates with it a number of features for use in a collaborative learning environment:

1. a two-part visualisation design to represent the structure as a network of concepts – concept space – and to allow each user to analyse structure relationships based on particular keywords – criteria space;
2. a 3D interactive visualisation to address the problems of cognitive overhead and information overload resulting from the structure complexity and multiple existing relationships. It also proposes a representation for exploring the structure;

3. a network support for sharing the structure for knowledge sharing;
4. a voting system to allow co-construction of the structure for knowledge sharing;
5. a chat system to support users comments and discussion;
6. an Information Visualisation within the criteria space to allow comparison of information about a data source with the structure for knowledge sharing;
7. a simple browser to display results from a data source based on search strings;
8. a textual search engine integration to use with the information visualisation and browse facilities The search engine software used was the *Altavista Search Personal eXtension 97*;
9. an interface to enter the knowledge structure allowing the input of a previous specified structure.

6.2.3 Prototype implementation

The structure for knowledge sharing has been implemented as a two-list structure, taking advantage of the structure elements presented in chapter 5, section 5.2.2. The structure for knowledge sharing contains the information needed to render the 3D interactive visualisations that are shared among users. The sharing of the structure is the responsibility of the server.

The implementation of the structure for knowledge sharing was designed to optimise network traffic. For example, the three versions of the *Information Management* structure presented in appendix A, are as follows: version with 17 concepts – 11KB; version with 30 concepts – 20 KB; and version with 45 concepts – 22 KB.

Based on Figure 31, the only service not implemented in the current ViDESK prototype is the annotation system. As the annotation facility does not affect the evaluation of the prototype it was not implemented in the current ViDESK version. The chat system and browser are modified third party code. The data source search engine is a commercial tool provided by Altavista, the *Altavista Search Personal eXtension 97*.

6.3 Using the prototype

6.3.1 The ViDESK visualisation design

VIDESK INTERACTION FACILITIES

Interacting with the prototype is largely through the mouse and direct manipulation facilities. The ViDESK prototype has a similar look and feel to typical Microsoft Windows applications.

The opening screen presents the ViDESK name and program credits (Figure 32).

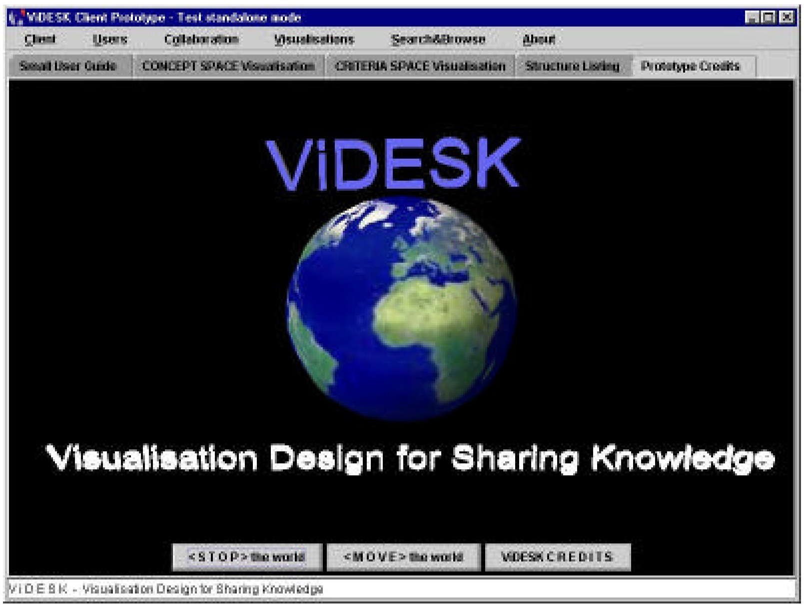

Figure 32: welcome screen in the ViDESK client prototype

The ViDESK client uses six pull down menus and five window tabs for presenting five simultaneous screens. Together, the *menus* and *tabs* provide access to user functionality available in the ViDESK client (Figure 33).

Figure 33: ViDESK client interface (menus and tabs)

The ViDESK client has the following six pull down menus (Figure 33):

- *Client*: with one option (*Exit*) that allows to exit the ViDESK client program.
- *Users*: with four options. The menu includes the options that provide information about users and access to the chat system. The options are: *User*

profile – redefine your user profile; *List active users* – gives a list of the users actually in the system; *List all users* – gives a complete list of the group users, and *Chat with other users* – to use the chat system facility, integrated with the ViDESK client.

- *Collaboration*: with five options. The menu contains the commands for proposing new structure elements. The options are: *Get structure elements* – forces an update from server of the structure for knowledge sharing; *Add concept* – add concept action; *Add keyword* – add a new keyword for an existing concept; *Alter keyword rating* – modify the current keyword rating in a concept, and *Add concept comments* – to use the annotation system (not implemented).
- *Visualisations*: with four options. This menu includes the commands related to the ViDESK visualisation. The options are: *Refresh Concept Space* – forces a redraw of the concept space visualisation, presenting the default perspective; *Select level relations to visualise* – allow to choose which of the four concept relationships levels are represented in the concept space visualisation; *Analyse one concept relations* – allow the selection of a particular concept and all its relations to other concepts, and *Define a new Criteria Space* – to input the criteria for the rendering of a criteria space visualisation.
- *Search&Browse*: with three options. The menu contains the options related to the search engine. The options are *Concept search* – generate a search string for a given concept and display the results in a browser; *Keyword search* – generate a search string for a given keyword and display the results in a browser, and *Use a search engine* – use of a ViDESK integrated browser featuring a search engine interface.
- *About*: with three options. This menu is related to credits, funding support and program identification. The options are: *Version* – display the ViDESK client version; *Credits & funding support* – display information about the ViDESK project, and *Feedback* – provides the email and World Wide Web address for comments and information about the ViDESK project.

The ViDESK client has five tabs for selecting different windows. The use of this kind of interface allows having more available screen area by superimposing several simultaneous screens and supports the two-part visualisation design as presented in chapter 5. The five tabs are the following (Figure 33):

- *Small User Guide* – a brief description of the ViDESK client program, for user reference.
- *Concept space visualisation* – the screen where the concept space visualisation can be explored.
- *Criteria space visualisation* – the screen where the criteria space visualisation can be explored.
- *Structure listing* – presents a textual listing of the structure for knowledge sharing. The concepts are listed on the left side of the screen and a complete structure listing with all the structure elements (concepts, keywords, and keyword ratings) is displayed on the right side of the screen.
- *Prototype Credits* – presents the ViDESK name and program credits and acts as the opening screen when entering the ViDESK client prototype.

Further description of the more important ViDESK client options is given in the following sections for each of the topics. The knowledge theme used in the following examples is the small version of the *Information Management* structure presented in appendix A.

An overall description of the ViDESK client prototype and brief user guide has been included. The *Small User Guide*(see Figure 34) tab contains an introduction of the prototype facilities in six help topics. These range from a general explanation of the aims of the prototype to the user visualisation controls. In the data display area, text is displayed every time users select a given topic.

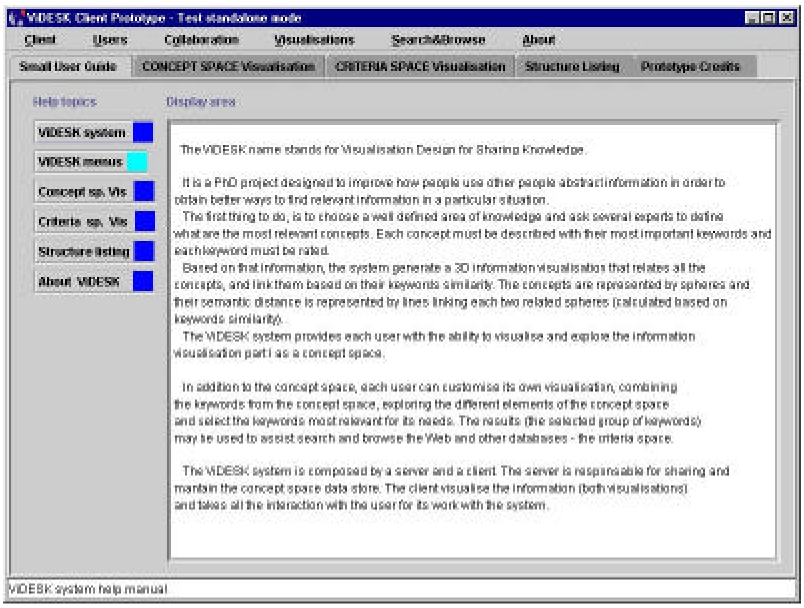

Figure 34: the *Small User Guide* tab

EXPLORE THE 3D INTERACTIVE VISUALISATIONS

Exploration is via a three-button mouse, sometimes along with a keyboard. Both the concept space and criteria space visualisations use the same controls for user navigation.

As a 3D space, the user needs to explore and move around the visualisation.
ViDESK client uses the mouse for allowing three basic operations to explore the 3D interactive visualisations:

- *Rotation*: left mouse button. Controls the rotation of the 3D interactive visualisations by dragging the left-mouse button.
- *Translation*: right mouse button. Allow the control of the translation in the (X, Y) plane. A drag motion using the right-button mouse can translate the 3D interactive visualisations.
- *Zoom*: central mouse button. Allow the control of Z-axis translation of the 3D interactive visualisations. The Z-axis translation is performed with a mouse drag motion using the central mouse button. If the mouse has just two buttons, the *alt key plus the mouse left-button* can be used (*alt-click-drag*)

KNOWING MORE ABOUT STRUCTURE ELEMENTS

Facilities to explore the structure for knowledge sharing are accessed through direct interaction within the visualisations, using mouse and keyboard commands. The two available ViDESK options in this area are listing concepts from the structure for knowledge sharing and a listing concept keyword and corresponding ratings. These two facilities complement the visualisations by providing more detail of the structure for knowledge sharing.

To list all the structure concepts for the knowledge theme, *shift key plus left mouse button* is used. A dialog is then displayed in front of the visualisation (Figure 35). The dialog box contains the concept listing, with concept name, type and description.

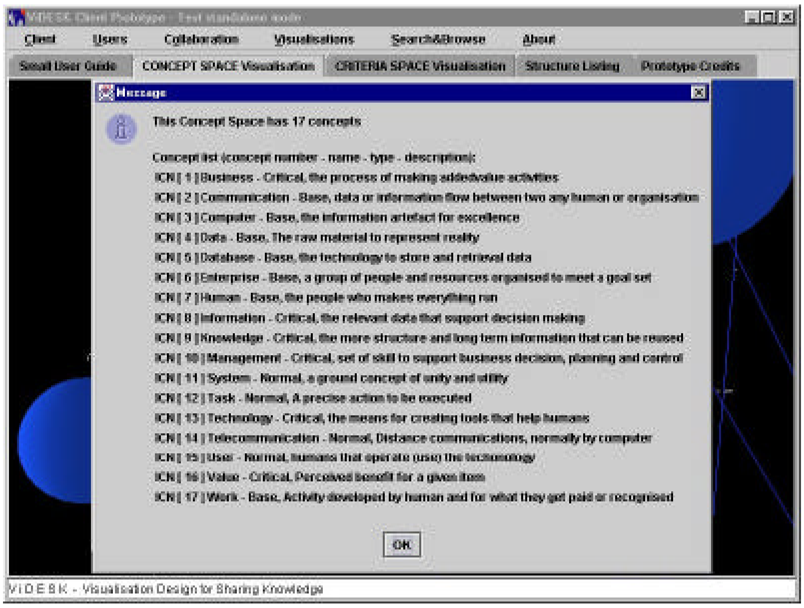

Figure 35: list concepts from the structure for knowledge sharing

To know more about a particular concept of the knowledge theme, the *left mouse button is double clicked.* An input dialog box prompts to enter a concept name. After entering a valid concept name, a dialog box with concept information is shown (Figure 36). The dialog box contains the complete keyword list with the corresponding keyword ratings for the entered concept. The information includes the concept name, type and its description.

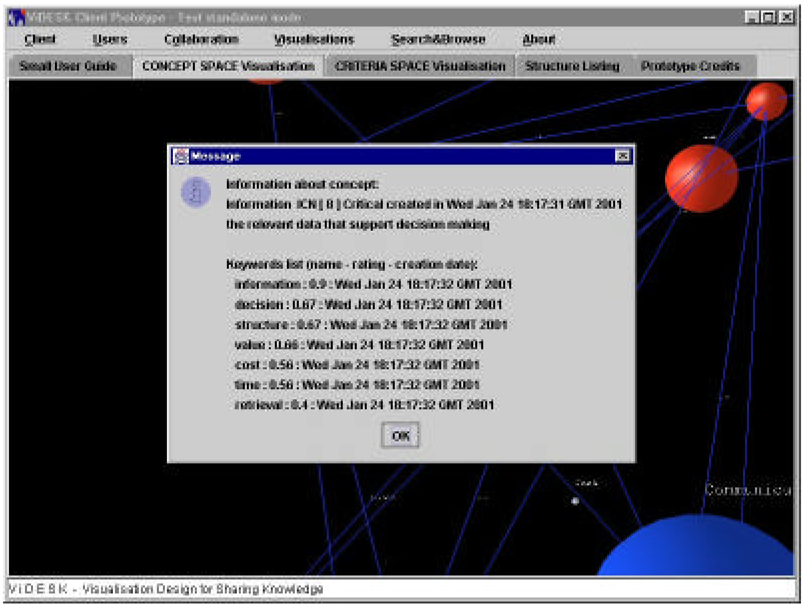

Figure 36: lists keywords and keyword ratings from a concept

The *Structure Listing* tab contains the textual description of the structure for knowledge sharing. The description contains the concept list and, for each concept, its keywords with the ratings and some additional information. The information is organised into two columns. The *available concepts* column lists all the available concepts in the structure for knowledge sharing. The *structure data* lists all the structure elements as shown in Figure 37.

The structure listing cannot be directly edited, but allows copying in order to transfer the text to other applications. However, from pilot testing, this facility was used in only two out of eleven trials and never after the first exploration of the visualisation design.

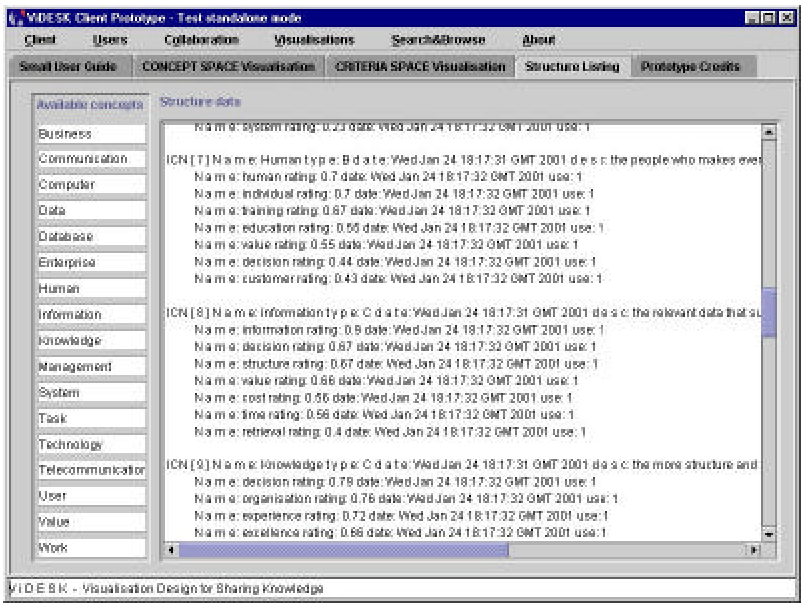

Figure 37: structure for knowledge sharing textual display

THE CONCEPT SPACE VISUALISATION

When selecting the *Concept Space Visualisation* tab (Figure 38) the 3D interactive visualisation is ready for user exploration. The concept space visualisation follows the model presented in section 5.3 – The visualisation design.

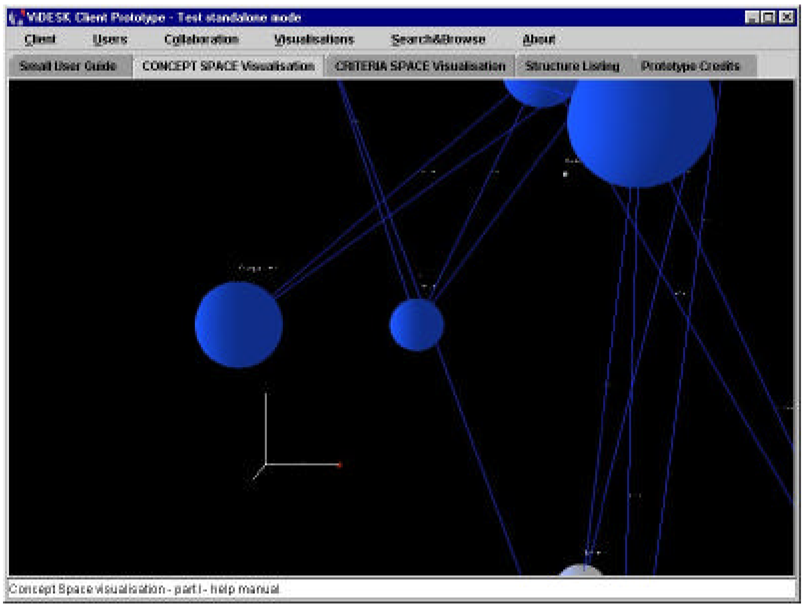

Figure 38: a view of the concept space visualisation

In Figure 38 all the used concept space visualisation symbols are displayed. Five spheres (concepts) are visible (at least partially) with two of the three available (concept type) colours on view. A number of lines, representing the semantic distance for each pair of concepts, are displayed. These lines show conceptual relationships.

The default view of the concept space visualisation shows the origin where the axes for orientation purposes are represented. Also by default, only some of the concept relationships are represented. The semantic distances represented are the strong ones (red lines) and upper medium ones (blue lines), when they exist.

To explore the concept space visualisation, additional support is provided by the *Visualisations* menu, as shown in Figure 39. The first three options are related with the concept space visualisation. The first option – *refresh concept space* – allows rendering of the concept space visualisation in the default perspective. Each time the concept space visualisation is rendered using this option, it shows the initial perspective (the one that includes the origin axes). Thus, the user can return to a known position, each time he/she feels lost in the visualisation.

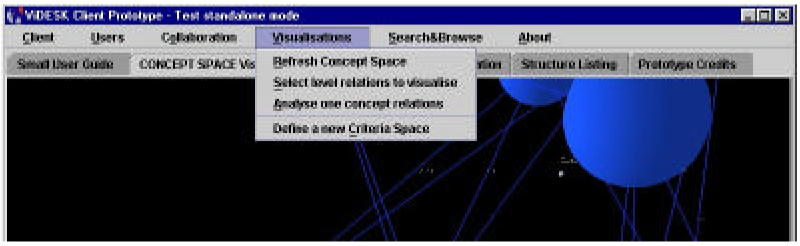

Figure 39: the *Visualisations* menu

Meaning of concept space visualisation symbols

The concept space visualisation uses a reduced set of symbols with precise meanings. When ViDESK is started or the concept space visualisation is refreshed, a small axis symbol is represented in the origin of the visualisation. This serves as a landmark. The X-axis has a small red sphere in its extremity. The Y-axis is vertical, and the Z-axis is positioned starting from the origin up to the user; when on this position, the 3D world is in the correct position to enable the labels to be read.

Besides the landmark for orientation support, the visualisation has only two more visual elements: the sphere and the line. A sphere represents a concept. Each sphere has one label associated with it that gives the corresponding concept name. Its colour denotes the concept type, critical (*red*), base (*blue*) or normal (*light blue*). The sphere size is related to the concept keywords and keyword ratings composition – the concept description rate. Sphere sizes vary from 0.1 up to 2 units of the virtual environment (corresponding to meters in the real world).

Although the the sphere size may vary as a function of the user's perspective and position in the 3D world, it can be used as an indicator of the concept composition. Figure 40 shows an example of a small size sphere resulting from a concept that does not have any associated keywords and keyword ratings. The concept named *Task*, despite corresponding to the first sphere being visualised, is the smallest among the four represented. Notice that the associated concept label denotes the proximity of the *Task* concept (we are close to this concept).

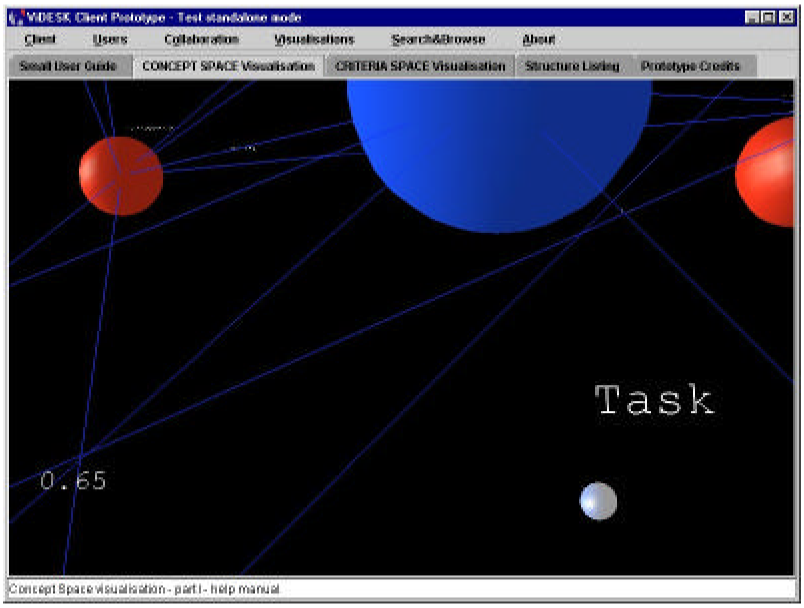

Figure 40: example of a concept without associated keywords

A line represents the semantic distance between spheres with values varying from 0 up to 1 representing the degree of relationship among them. A line always starts in one sphere and finishes in another. Each line has a label indicating the corresponding semantic distance value, placed in the middle of the line. The lines are colour coded to facilitate the identification of the semantic distance value. Four colours are used for identifying four levels of semantic distance values, as presented in chapter 5, section 5.3. Figure 38 and Figure 40 give examples of the symbols used in the concept space visualisation, including the lines.

Dealing with concept space visualisation complexity

With the increase of the number of concepts in the structure for knowledge sharing, the number of its relationships also tends to increase. An increae number of semantic distance values greater than zero and the number of visible lines will make the concept space visualisation less easy to understand and explore. By default, the concept space visualisation includes only the lines representing upper medium relationships and strong relationships.

To analyse the existence of other relationships, there are two options in the *Visualisations* menu (Figure 39). These options are the *Select level of relation to visualise*, and *Analyse one-concept relation*.

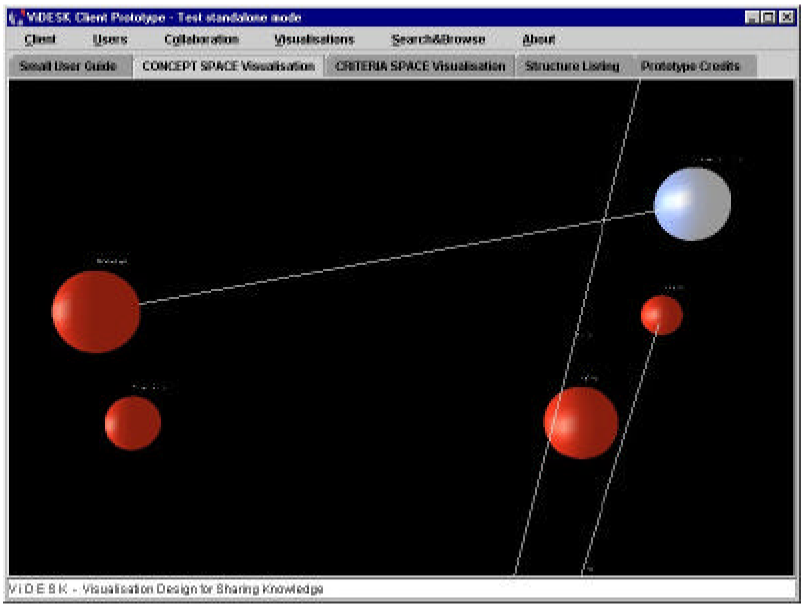

Figure 41: visualise small relations

The *Select level relation to visualise* option filters each one of the four colour line types to be visualised. Figure 41 shows one example of displaying the significant relations, where only the white lines are represented.

Figure 42 shows the same concept space visualisation area, but this time with lower medium relations displayed. If Figure 41 and Figure 42 are compared, the number of represented lines and respective colours are different but the spheres characteristics remain the same (size, position and colour). Notice that between the same concepts there is no more than one line (regardless of its colour).

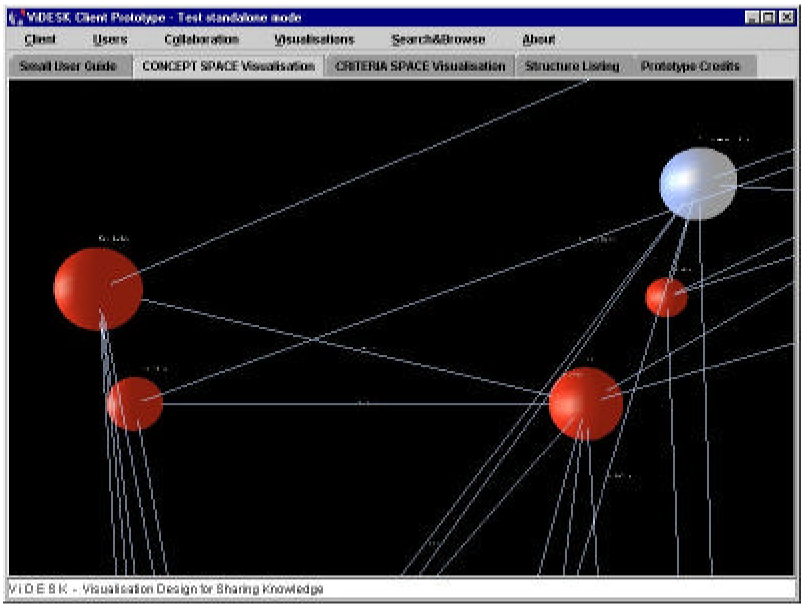

Figure 42: visualise lower medium relations

The *Analyse one concept relation* option from the *Visualisations* menu (Figure 39) allows the user to see only the relations of the specified concept. Figure 43 shows an example of the concept *Data* of such a visualisation. Between all the other concepts, relations are visualised as in the default concept space visualisation.

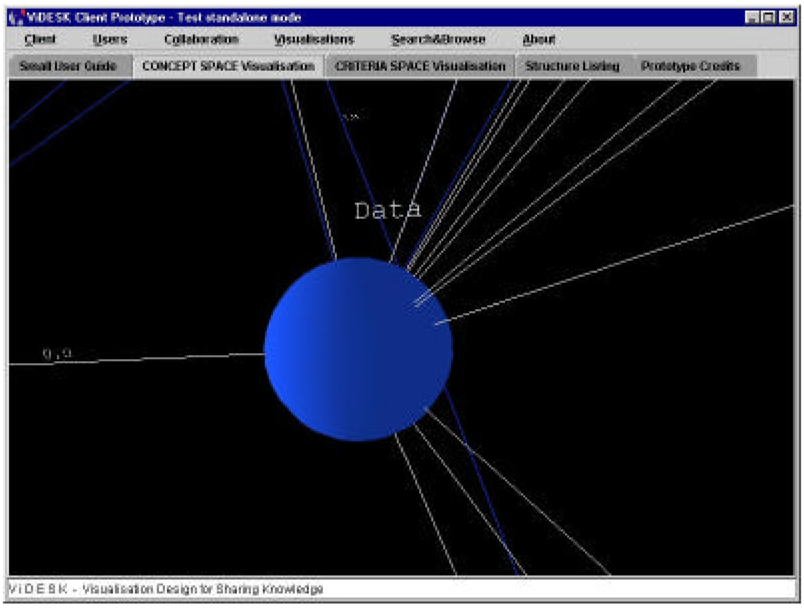

Figure 43: visualise all relations for the *Data* concept

THE CRITERIA SPACE VISUALISATION

When selecting the *Criteria Space Visualisation* tab (Figure 39) only the axes are represented, along with a label indicating that no criteria are selected. This is the initial criteria space visualisation, before entering any criteria (Figure 44). The criteria can be entered using the *Customise Criteria Space* option from the *Visualisations* menu (Figure 39).

The criteria space visualisation is an alternative way of visualising the structure elements. It uses spatial positioning for grouping concepts based on three criteria entered by the user and these can be entered as many times as wished. The criteria space visualisation was introduced in chapter 5, section 5.3.3.

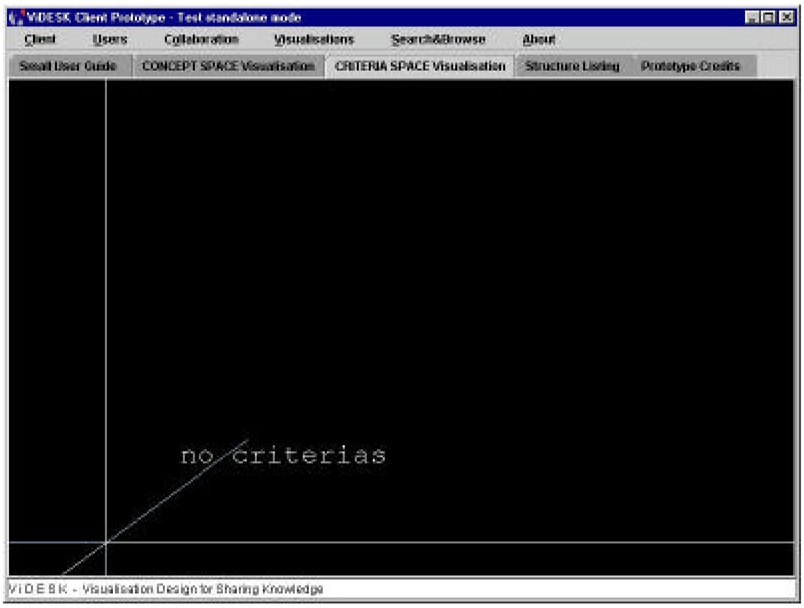

Figure 44: initial criteria space visualisation

To explore this 3D interactive visualisation the same controls are used as for the concept space visualisation. For landmark purposes, the X-axis has a small red sphere in the extremity. The positive section of an axis is visualised in white, while its negative part is *light blue*. At positive extremity of the axes the criteria name label appears. Text labels in the Criteria Space visualisation are readable when the X axis is displayed with the red sphere to the right and the Y axis is positive side upwards.

The criteria space visualisation has the axis represented and all its symbols in a limited space defined by the axes. Note that all the spheres are the same size but maintain their colour code as in the concept space visualisation. The example in Figure 45 uses the following criteria: *information*, *management* and *cost*. The criteria input can be a given keyword or no input at all. If no criterion is specified for a given axe, the *Criteria Space visualisation* uses only the two other axes for placing the concepts.

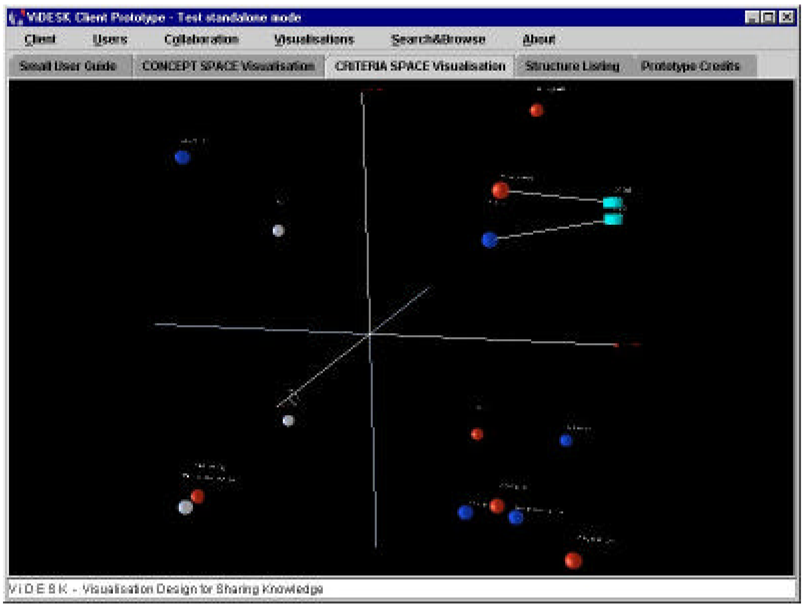

Figure 45: criteria space visualisation

The spatial position is important in the criteria space because it provides information about the rating, for each of the criteria, of concepts. The existence of the criteria for each concept supports the placing of the concept for the corresponding criteria according to the concept' keyword rating. If the criteria do not exist for a concept, the resulting criteria value assigned is -1. This means that the concept will be placed in the negative side of the corresponding criteria axis. The three available axes can be arranged in eight possible ways – each named as an octant. Figure 46 shows a perspective of the criteria space visualisation in Figure 45, where the concepts distribution in the eight octants is more visible.

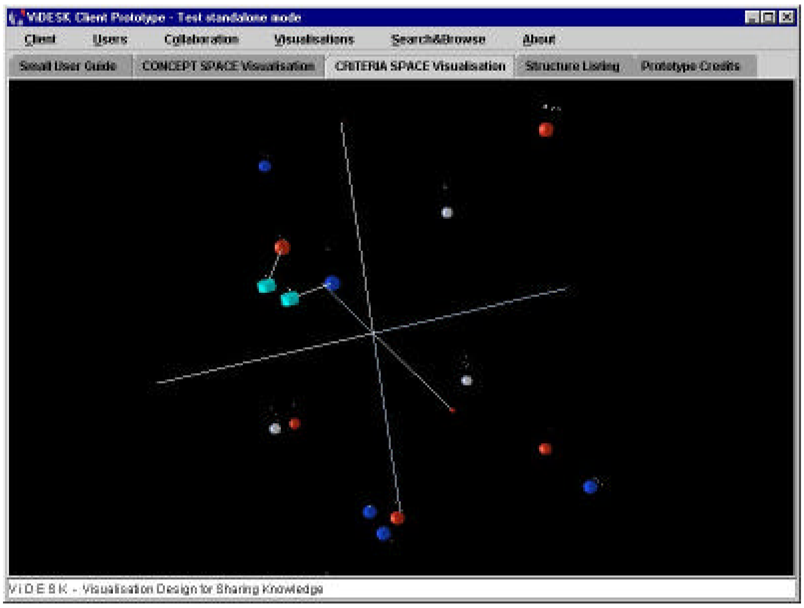

Figure 46: criteria space visualisation octants

Among the eight possible octants in the criteria space visualisation is the octant that corresponds to the situation where the three criteria are not satisfied. All the spheres are in the same place, causing their labels to form a label list up the sphere representation (Figure 47), meaning that among the 17 concepts in the structure, four concepts (*Task*, *System*, *Human* and *Data*) have none of the criteria.

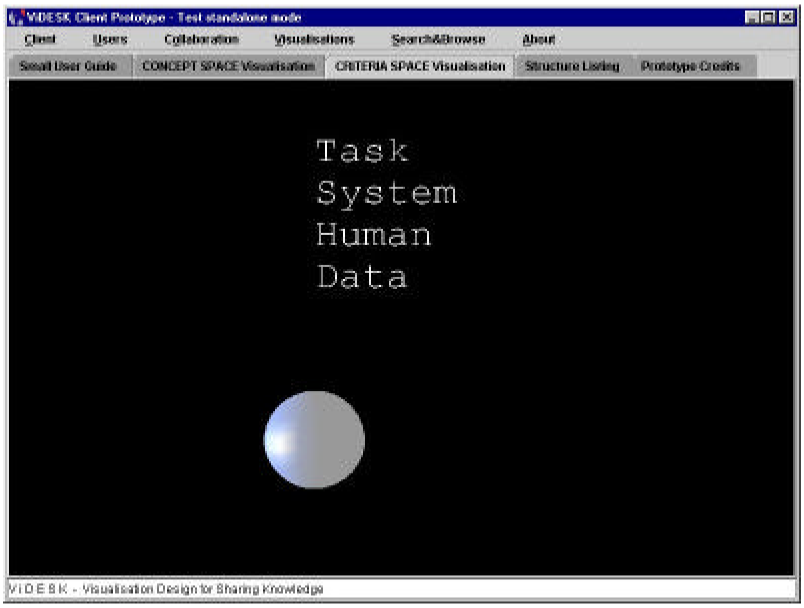

Figure 47: criteria space octant or the no satisfy criteria

Figure 48 shows a further example of a particular octant in the criteria space visualisation where six concepts are visualised with different, but close, spatial positions.

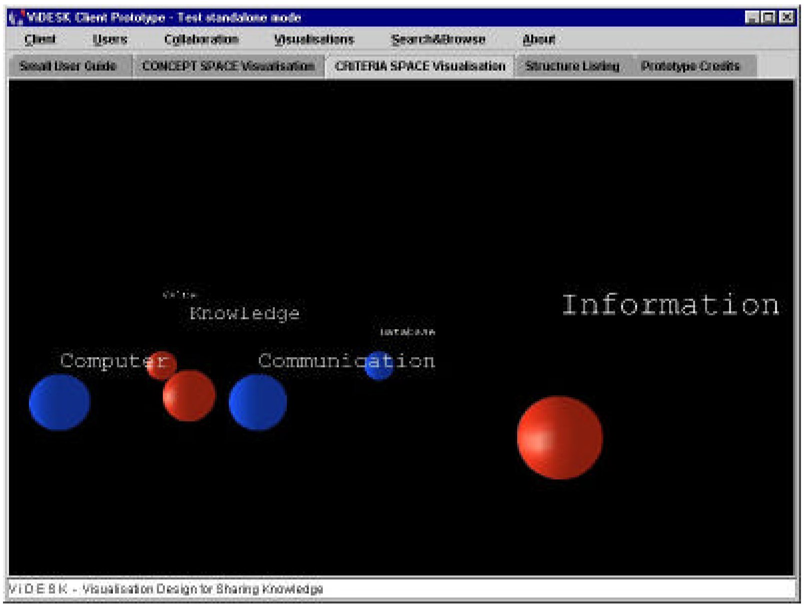

Figure 48: The placing of the concept spheres in the Criteria Space visualisation

From Figure 48 some observations can be made. A group of four concepts (*Information*, *Communication*, *Knowledge* and *Computer*) have both criteria *information* and *cost* but not the *management* criteria. These four concepts are closer to the Z-axis. A second group with two concepts (*Database* and *Value*) is also visualised but in a more distant position on the Z-axis, which has the *cost* criteria assigned. Thus, this two-concept group shows only one criteria: *information*.

6.3.2 ViDESK interaction with data sources

THE VIDESK INFORMATION VISUALISATION

Within the criteria space visualisation it is possible to compare the concepts that meet all the criteria with a data source as described in chapter 5, section 5.4.2.

This ViDESK facility allows analysis and how much information from the data source is related with the structure for knowledge sharing regarding the selected group of concepts that met the criteria. Figure 49 shows an example of a criteria space visualisation with an information visualisation that provides the image based on the data source for the two concepts (*Business* and *Work*) that meet all the three criteria. The occurrences for each concept differ, with *Business* having the higher number of hits – *1294*. These values are obtained by querying the data source using each concepts' keyword list.

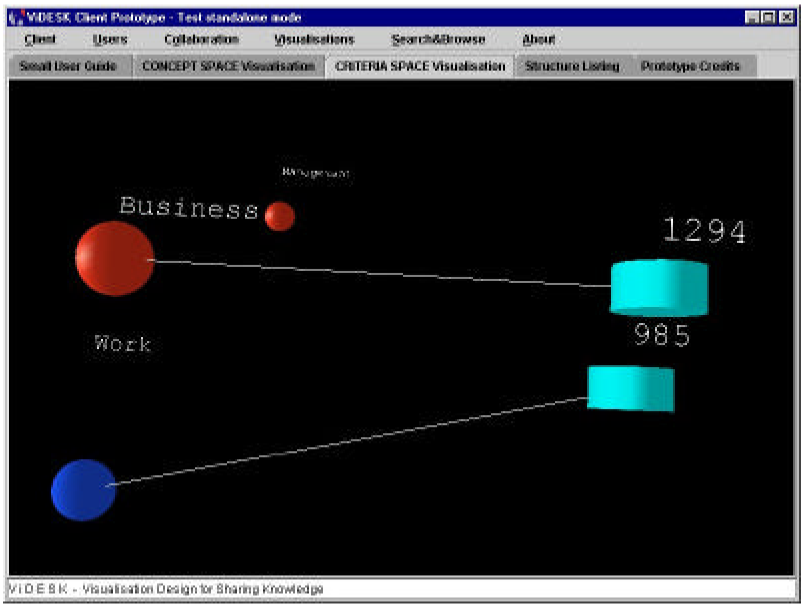

Figure 49: criteria space visualisation with the information visualisation

As seen in Figure 49, two additional symbols are used to represent the information visualisation. The cylinders have labels to indicate the total data source hits for the concept to which it is linked to by a white line. All cylinders are the same size and green colour (the 3D perspective effect could provoke apparently different sized cylinders). The spatial positioning of the cylinder results from using the concept's keywords that meet the criteria and calculate their relative rating considering the total number of hits.

VIDESK INTERACTION WITH A DATA SOURCE

The system provides a means of producing textual output that supports the creation of queries based on the structure for knowledge sharing and the display of results. These facilities are placed under the *Search&Browse* menu (Figure 50).

Figure 50: the *Search and Browse* menu

The *Search&Browse* menu features three options: *Concept search*, *Keyword search*, and *Use search engine*. The first two deal with the generation of search strings for querying the data source, and the other option allows the use of a Web browser featuring a search engine – the *Altavista* search personal eXtension 97 (Figure 51).

Figure 51: the *Altavista* search personal eXtension 97

ViDESK uses the structure for knowledge sharing to find relevant information by organising groups of keywords related to user input. Two types of ViDESK textual output are available.

The first search type uses the concept collection of keywords to compose a query. The user enters the chosen concept and a textual string is generated, and used as a search string to display HTML window with search results from the data source. Figure 52 shows the results of a concept search performed using the *Information* concept, showing the keywords associated with the concept *Information* in the submit field of the search engine interface.

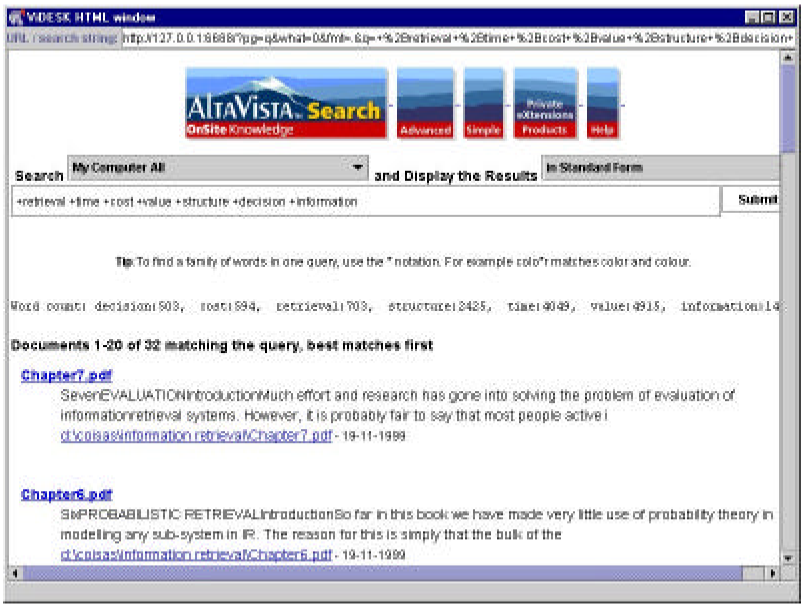

Figure 52: a results window for a *concept search*

The other search type is based on a given keyword. ViDESK allows the user to enter a keyword and based on that keyword, a textual output string is generated as a collection of related keywords – as described in chapter 5, section 5.4.3.

Gathering the most highly rated keywords in all the structure concepts that have the inputted keyword on its keyword list makes the keywords collection. Figure 53 shows the results of a keyword search performed using the keyword *management*.

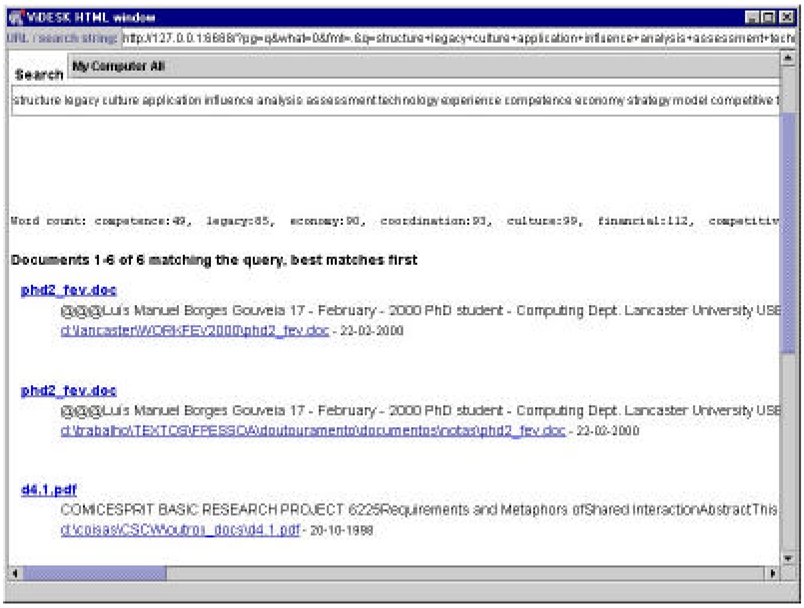

Figure 53: a keyword search results window

6.3.3 ViDESK sharing facilities

INTRODUCTION

One of VIDESK's facilities is that users can collaboratively modify the structure for knowledge sharing. A server is thus needed to address both user *awareness* and structure *sharing*.

The *Users* menu (Figure 54) provides three groups of facilities to support user information. Information about the user itself, with the *User profile* option; and other users information with two options that list the active users and all the users registered in the group – the options *List active users* and *List all users*, respectively. The last of the three groups of options is a chat system that allows supporting users synchronous discussions as a complement to the voting process – *Chat with other users*.

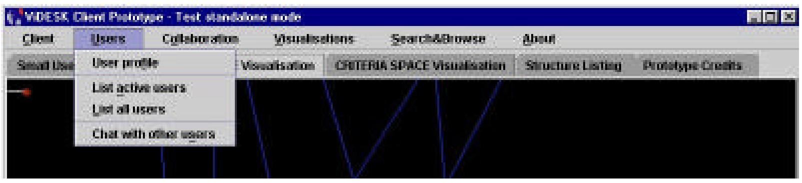

Figure 54: the *Users* menu

The *Chat with other users* option accesses a chat system that enables discussion between all the active users, through a text message broadcasting. Each time a user wants to send a message, the correspondent text is echoed for all users. The messages are displayed in a scroll window. The chat system was developed and based on code provided by Farley [Farley, 1998].

STRUCTURE ENHANCEMENT

For structure enhancement, any user can propose new concepts, new keywords and alterations to existing keyword ratings. Each user proposal is voted on, and if the majority of people (greater than 50%) accept the proposal, then the structure is changed accordingly.

The *Collaboration* menu (Figure 55) groups the user options related to the structure for knowledge sharing. The first option on the *Collaboration* menu – *Get structure elements* – enables the user to force the updating of the structure for knowledge sharing from the server – it provides an alternative to the automatic updating provided by the server. The last option *Add Concept comments* provides access to the annotation system. This option has not been implemented in the current prototype version.

Figure 55: the *Collaboration* menu

When a user selects the option *Add CONCEPT*, from the *Collaboration* menu, he/she is requested to input a name for the concept, its type, concept description and concept spatial position. The input of the concept spatial position in the concept space visualisation is given by an initial position, a direction and a distance factor, as described in section 5.3.2.

When the user selects the option *Add KEYWORD*, from the *Collaboration* menu, he/she is requested to input the name of the concept and to add the keyword, the keyword name and the associated keyword rating.

When the user selects the option *Alter KEYWORD rate*, from the *Collaboration* menu, he/she is requested to input the name of the concept to which the keyword belongs, the keyword name, and the new keyword rating.

Based on the input given by the user, the voting system broadcasts the information and waits for all users to vote. It then implements the proposal, if the majority of the users have voted *yes*. Figure 56 presents a proposal to add a concept. The window shows information about the proposal and the support for the three available options to vote: *yes*, *no* and *neutral*. To submit the user vote it is necessary to press the *Submit vote* button, which causes the voting option to be sent to the server and closes the voting window. For other actions (add a keyword and altering an existing keyword rating) the voting window is similar.

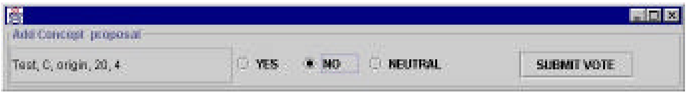

Figure 56: the voting window for a new concept proposal

The voting window does not block the visualisations. This supports user decisions based on more exploration of the structure and available 3D interactive visualisations. Figure 57 shows the voting window in front of the concept space visualisation allowing the user to interact with both windows as desired.

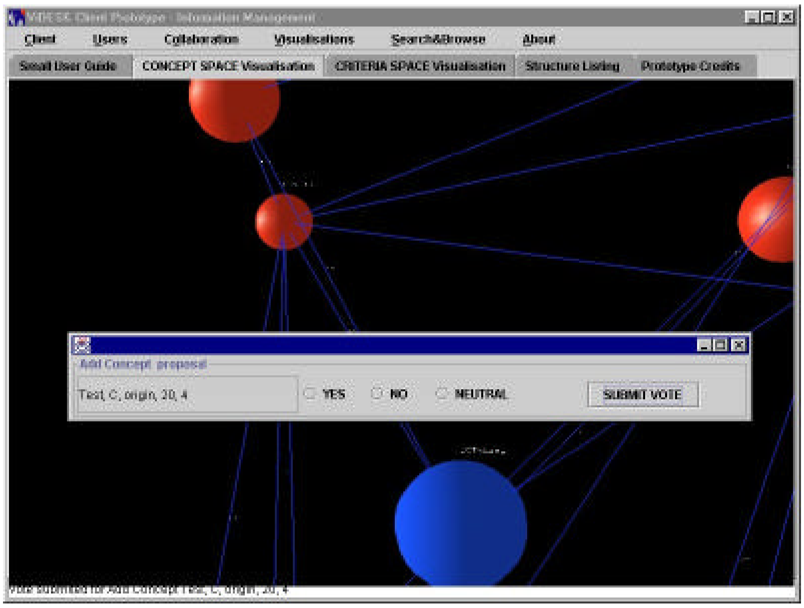

Figure 57: the voting window and ViDESK prototype simultaneous access

Following a vote, the system notifies users of voting results, presenting the information of the action proposed and the number of votes for each of the available options. The system also informs if the proposal was accepted or not (Figure 578).

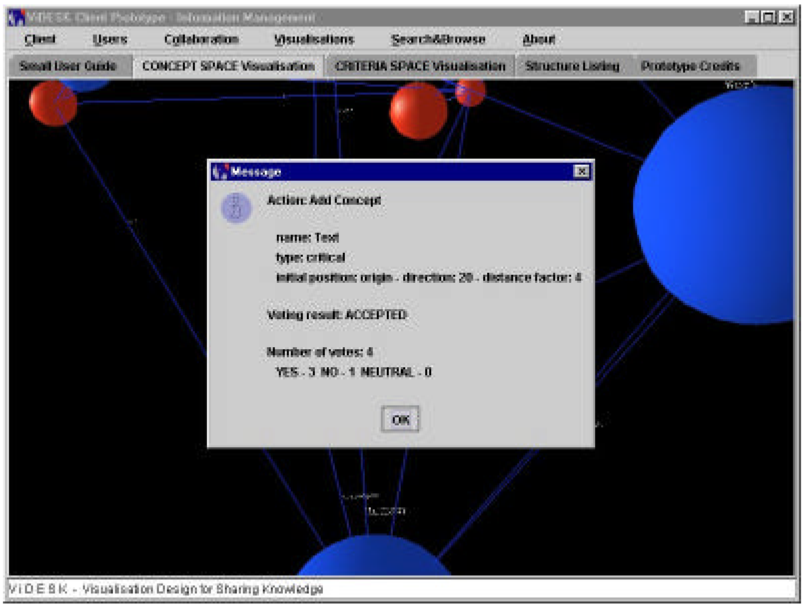

Figure 58: user notification window for the voting system

VIDESK SERVER

To support sharing, the ViDESK prototype includes a server. The ViDESK server is responsible for maintaining the structure for knowledge sharing updates for all users by keeping track of structure enhancement. The ViDESK server features three pull down menus and four tabs (Figure 59).

Figure 59: ViDESK server interface (menus and tabs)

The ViDESK client has the following three pull down menus:

- *System*: which includes four options. The options are: *refresh concept space visualisation* – used to update the visualisation test within the server; *ViDESK description* – a description of ViDESK; *Start server service* – command to begin the server service, following input of the name of the knowledge theme to be shared; *Stop server and exit* – closes the server application and stops the server.
- *File logs*: with two options. They are: *Backup logs* – allowing to backup the log files used in the server; and *Reset logs* – deletes all information from existing logs. The user can input which of the four logs to backup or reset.
- *About*: with three options. This menu is related to the credits, funding support and program identification. The options are: *Version* – display ViDESK server

version; *Credits & funding support* – displays information about ViDESK, and *Feedback* – email and World Wide Web address for comments and information about ViDESK.

The ViDESK server five window tabs are:

- *Small Guide* – providing a description of features and their use. The tab content is displayed by default when the ViDESK server is started. The small guide tab is similar to the one in the ViDESK client. (Figure 34).
- *Structure manager* –allows the modification of the structure for knowledge sharing in alternative ways to collaborative enhancement. More commands are provided than are for collaborative enhancement. Among these are the ability to delete concepts and keywords. The structure manager (Figure 60) can be used to input a new structure and manage existing structures.

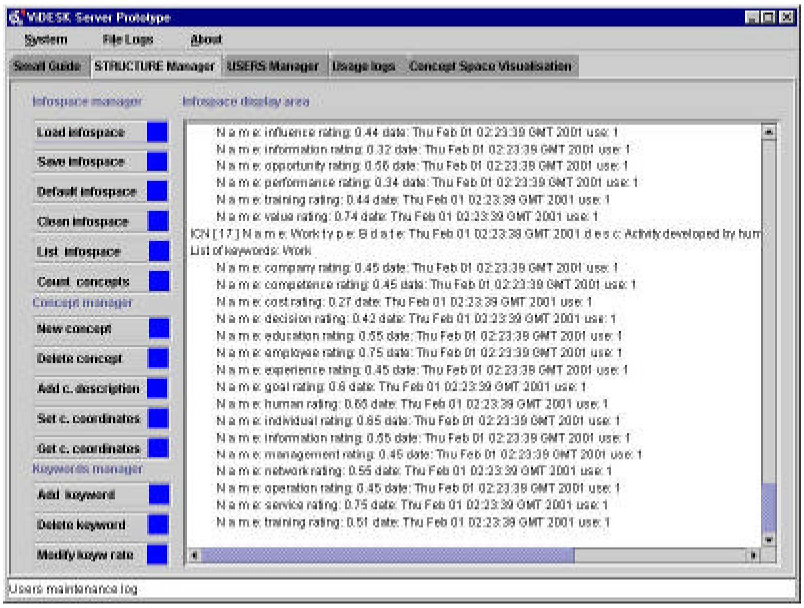

Figure 60: the structure manager in ViDESK server

- *Users manager* – this window comprises the management of information about the users identification and personal information. Information stored includes a password to log in the server. The user manager has facilities to *add* and *delete* users, and maintains information on up to twenty users. Figure 61 shows the users manager with all the available actions and a list of users.

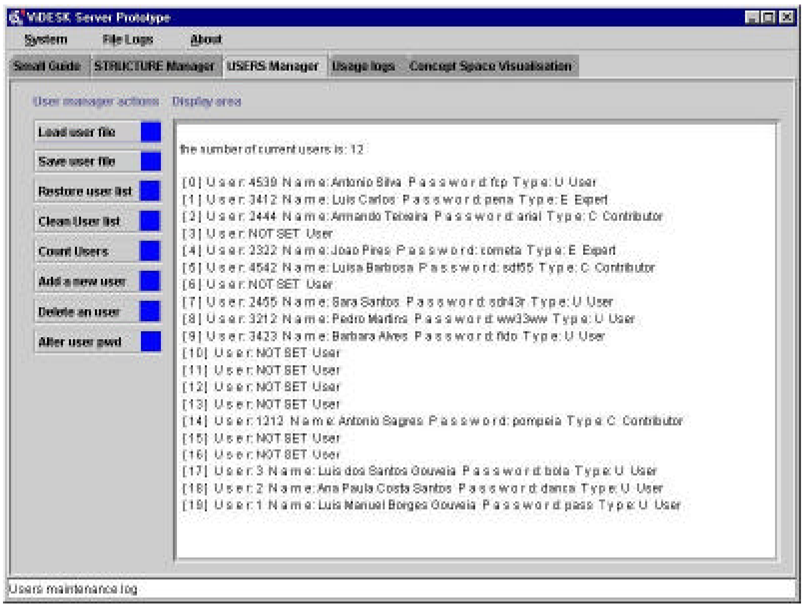

Figure 61: the users manager facility

- *Usage logs* – allows the maintenance of four log files. The log files are the server activity log, structure manager activity log, the users manager log, and the structure enhancing log. The first three provide information on the use of the ViDESK server, the last provides information about enhancements to the knowledge structure.
- *Concept space visualisation* – the concept space visualisation tab enables the testing of the visualisation rendering. All the levels of relation are represented in this version of the Concept space, as shown in Figure 62. This version of concept space visualisation is used mainly for testing purposes.

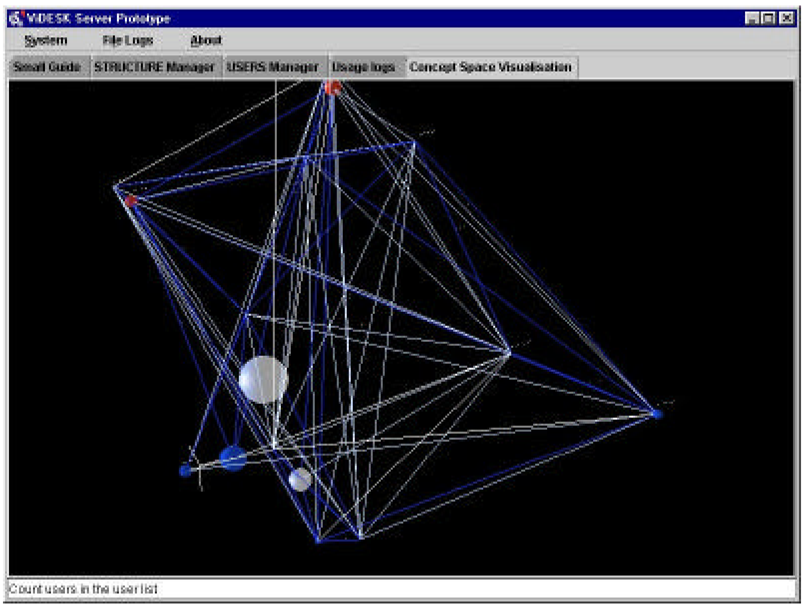

Figure 62: the concept space visualisation version in ViDESK server

After starting the ViDESK server, the option *start server service* from the *system* menu must be selected.

Figure 63: the start server service option

When selected, the option for starting the server service (Figure 63) requests a label to identify the structure to be shared. When the ViDESK client logs the server, the structure for knowledge sharing is passed and the input name is placed in the window title, as seen in Figure 58 for the *Information Management* example. Note that the ViDESK client can be run in stand-alone mode without sharing the structure. In this case, the window title appears as in Figure 55, with the label *test standalone mode*.

6.4 A user scenario

INTRODUCTION

The following user scenario provides a general description of the use of ViDESK to support collaborative learning. The group has four people: one lecturer – John, and three students: Mary, Tom and Luis. The knowledge theme is *Information Management*. John wants his students to discuss the two first modules of the Information Management class: *Information Management introduction* and *the business and enterprise practice*. The Information Management class is part of a Communications Engineering major degree scheme. The class goal is to consider information as an economic resource that needs to be planned, evaluated, controlled, and managed.

So, John's goal is to provide technical students a different perspective to deal with information and information needs – an enterprise-based perspective. This must be done with the contribution of all group members, who discuss the concepts and form their own mental map of the knowledge theme, in order to maximise learning of the underlying concepts. The group is requested to enhance a structure for knowledge sharing to further develop their knowledge about *Information Management*.

The group will use the system to elaborate a common structure for knowledge sharing and be involved in the construction of a common mental model for the knowledge theme. Each individual is expected to explore and contribute to the structure for knowledge sharing. Each individual effort brings to the group new sources of information that can be useful to support learning and show others' perspectives.

As the lecturer, John has to produce an initial description of the knowledge domain as covered in the two class modules. He lists concepts, and for each concept, lists a set of keywords that describe the concept. To each keyword he associates a rating to provide an indication of the keyword association to the concept

The initial structure also specifies the position of each concept for the concept space visualisation. This initial structure provides a context for the knowledge being shared and discussed.

John has an alternative for the initial structure – an empty structure. An empty structure has no structure elements (concepts, keywords and keyword ratings). In this case, each group member is involved in building the structure for knowledge sharing from the beginning. This represents a greater effort and requires better knowledge of the knowledge theme.

The students, Tom, Luis, and Mary already possess some understanding of the above concept space, resulting from the first two lectures on the *Information Management* module. The group has two main goals:

- enhance the structure for knowledge sharing in order to fully enrich it based on common agreement;
- learn about *Information Management* concepts by exploring the system and contributing to group discussion.

START USING THE ViDESK SYSTEM

John used one of the school computer labs where all four group members can access the system. John has organised with the local technical staff the software installation: ViDESK server and four ViDESK clients, one for each of the users, including himself. The lab allows the use of four personal computers in a local network with access to a server where the ViDESK server software is installed.

John uses the ViDESK server to input the initial structure for knowledge sharing and user' related information. He also starts the server service with the structure to be shared, labelling it *Information Management*. The server for the chat system is also started.

Each user starts a ViDESK client and logs in to the system by entering their student identification number and password (Figure 64). The ViDESK server checks user identification and password. If both identification and password are valid, the ViDESK server returns the structure for knowledge sharing and the structure label. With these elements, the ViDESK client is started and the first credits window tab (Figure 32) is displayed. From now on, the ViDESK client is ready for use.

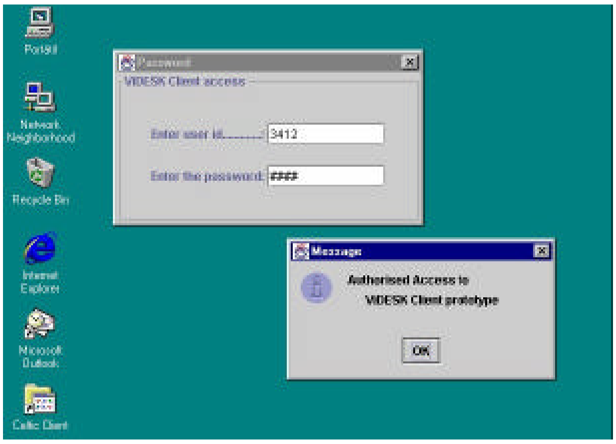

Figure 64: ViDESK client login

Tom chooses to browse the small user guide (Figure 34) that gives an introduction to the commands and options of the ViDESK client. Luis and Mary choose to explore the structure for knowledge sharing. Luis selects the structure listing (Figure 37) to have a textual introduction to the structure. Mary chooses to explore the concept space visualisation (Figure 38).

By now, all group members are logged into the system; John included, and has access to the ViDESK client facilities. John reminds the group that they should focus on exploring the structure for knowledge sharing, and on the conceptual relationships.

John invites each user to explore the *concept space visualisation*. He does that because each user needs to know more about the structure in order to be able to discuss it.

ViDESK USE

Tom explores the overall structure elements by using the concept space visualisation. He zooms out and tries to locate the red spheres that are the critical concepts of the structure (Figure 65). Tom discovers that there are just six critical concepts – using the system facility to list all concepts (Figure 35), which are all in the same region of the concept space visualisation.

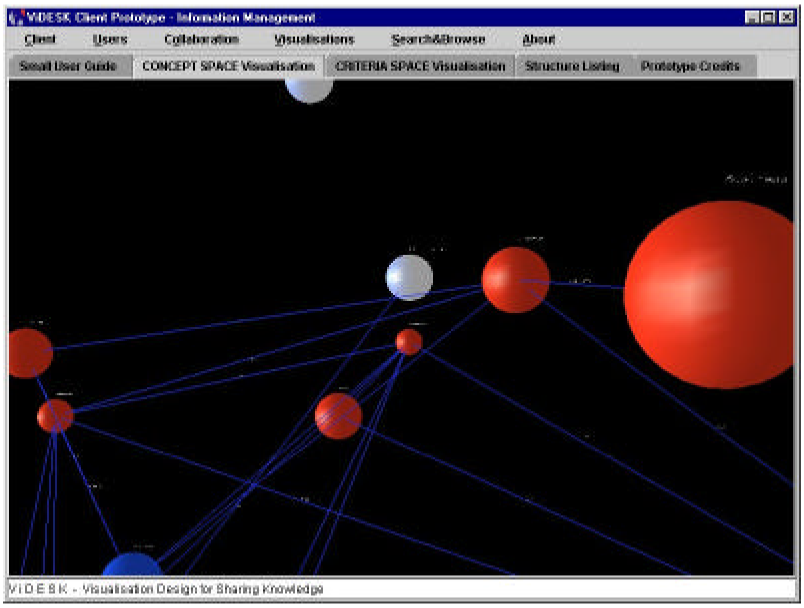

Figure 65: looking for the Information Management critical concepts

Mary looks for the relations between some of the concepts. Mary knows that concept relations are represented as lines and that they result from keyword similarity between concepts.

In particular, Mary examines the *Human* and *Work* relation (Figure 66) with a semantic distance value of (*0.59*). Based on this Mary knows now that there is a relation between *Human* and *Work* within the context provided by the structure about Information Management.

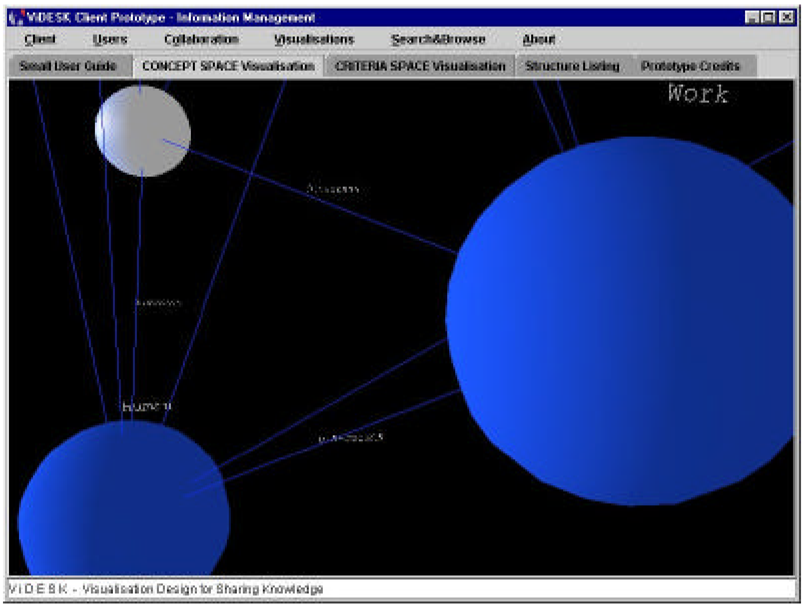

Figure 66: analysing relations between concepts

Luis analyses how the *Computer* concept is related with other concepts in the structure. He uses the option from the *Visualisations* menu that allows the analysis of conceptual relationships. When exploring the concept space visualisation, Luis finds that the *Computer* concept has five relationships with different semantic distance values: two of them are upper medium, another two lower medium and the last is small, Figure 67.

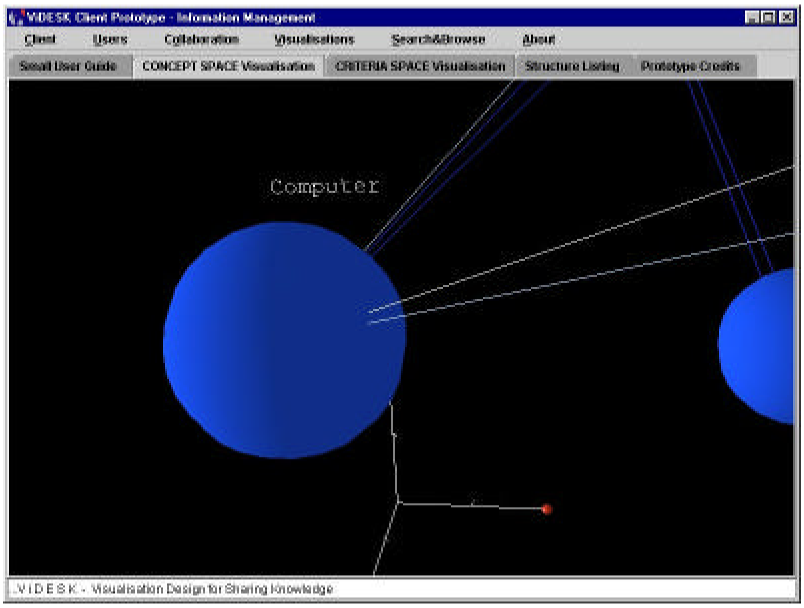

Figure 67: analysis of *Computer* relations in the structure

John asks his students to explore the structure for knowledge sharing using ViDESK client facilities. These facilities include the 3D interactive visualisations, the structure listing and the interactive options for further exploring the structure about the Information Management.

Mary checks how concepts are related based on the criteria *information*, *structure*, and *value* (Figure 68). Mary finds out that two (*Business* and *Information*) of the 17 concepts have, in their keywords, the ones specified as criteria. Mary also notices that the other four critical concepts other than the ones in the first octant do not have the keyword *structure* in their keyword group. The first octant is the one with the two critical concepts (red spheres) linked with the cylinders (Figure 68).

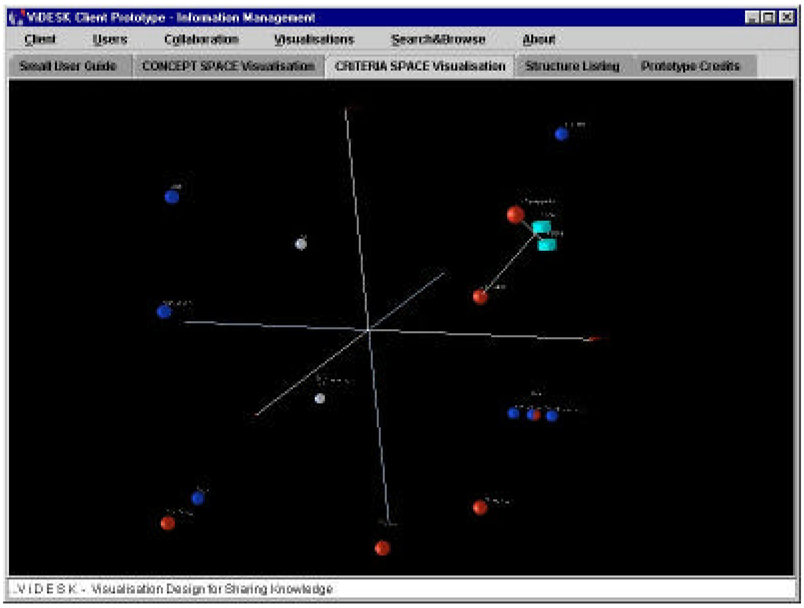

Figure 68: criteria space visualisation for *information*, *structure* and *value* criteria

Taking into account the criteria space visualisation from Figure 68, Mary finds that the existing cylinder symbols of the two concepts have the same hit values – *1294* – which potentially means that their data source results can be similar. This occurs because performing the corresponding concept searches for these concepts return the same number of results, although they are different results as shown by the cylinders slightly different positions. Luis also uses the criteria space visualisation to find further relations between concepts based on their similar keywords. Luis used *data*, *information* and *value*, which provided the criteria space visualisation in Figure 69.

Luis finds out that none of the structure for knowledge sharing concepts met all the criteria, which indicates that there are no concepts with the *data*, *information* and *value* keywords together. Luis establishes that all the critical concept does not have the *data* keyword on their keyword groups but that five of the critical concepts have the *information* keyword (the exception being the *Technology* concept).

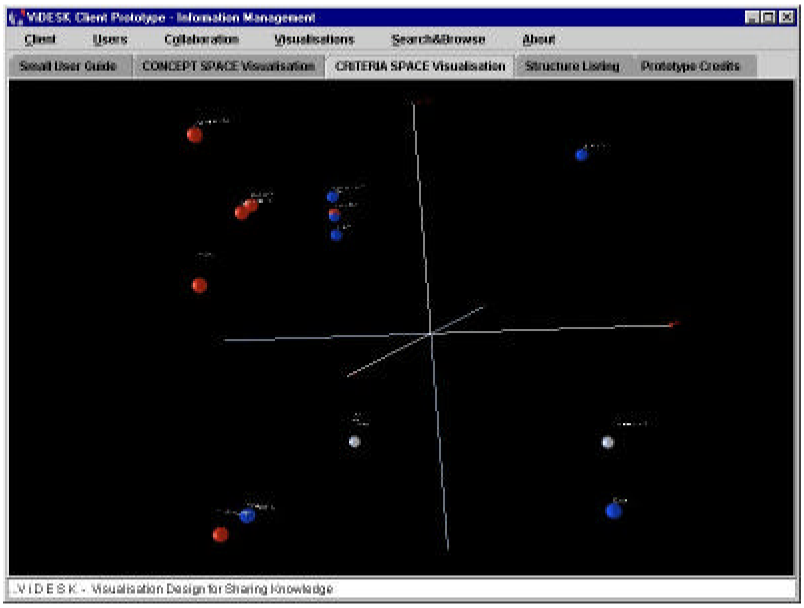

Figure 69: criteria space visualisation for *data*, *information* and *value* criteria

Tom relates to the *information* and *value* criteria without specifying a third criterion, as visualised in Figure 70. Because Tom has just introduced two criteria, concepts are positioned in a plane composed of the *information* and *value* criteria. Four concepts meet the criteria: *Business*, *Information*, *Management* and *Value*.

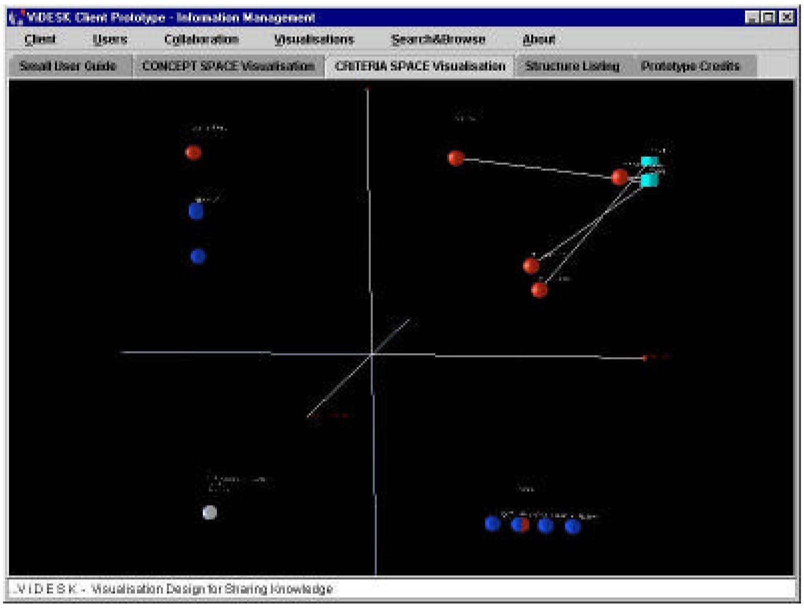

Figure 70: a criteria space for the *information* and *value* keywords

Tom managed to relate four critical concepts from the *Information Management* theme. He also discovered that although each concept has a different number of hits in the data source, the associated concepts are close to each other. This may indicate that for the data source there are no differences in searching occurrences for each of the concepts. To test this hypothesis Tom used the *Search&Browse* menu (Figure 50) with the option *concept search*, enabling him to see the data source results and compare them.

Luis tries to make some searches for its local data source, based on both the concept and keyword search facilities from the *Search&Browse* menu. ViDESK uses these facilities to detect if some of the occurrences of the data source have relevant information in the context of the structure for knowledge sharing.

After exploring the ViDESK visualisation design, Tom, Mary and Luis have a better understanding of the available network of concepts and their relationships as their discussion in the chat system seems to show. This will allow them to participate in the construction of the structure for knowledge sharing by using the *Collaboration* menu (Figure 55).

STRUCTURE ENHANCEMENT

John proposes a new concept. He does this based on his analysis that most of the critical concepts have some kind of relationship with *information* and *value*. John proposes a concept named *Work*, defining it with a brief sentence, its type and position in the concept space visualisation. The proposal is placed for voting as shown in Figure 71.

To support the proposal of a structure enhancement as John did, users should take advantage of the chat system to introduce and discuss their proposals. Figure 75 shows a text log for the structure enhancing discussion.

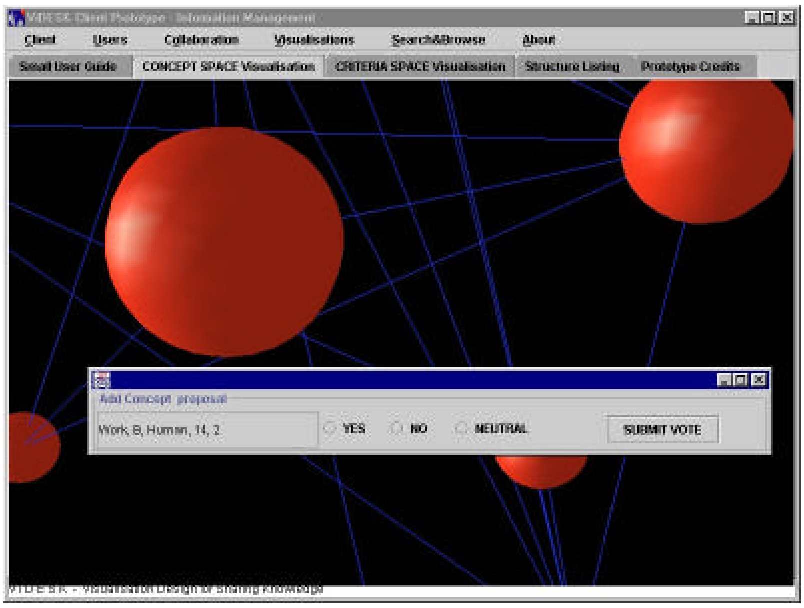

Figure 71: asking for a vote on the new concept proposal

The voting process ends with the results gathered by the ViDESK server and returned to each ViDESK client as shown in Figure 72. The voting results notify that the new concept *Work* is accepted and the structure for knowledge sharing updated accordingly in the server. All the users will receive the new structure that includes the new concept from the server.

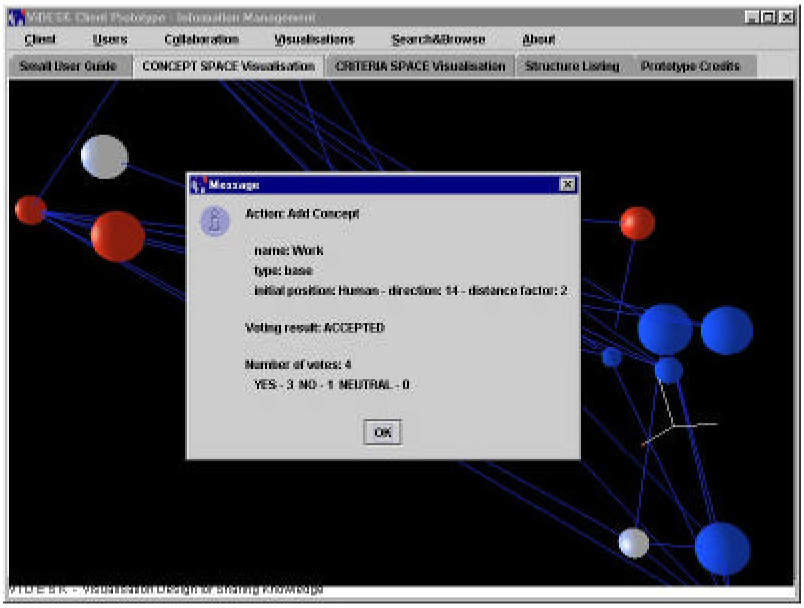

Figure 72: a voting display results from the concept proposal

Tom performs an add keyword proposal regarding the *Task* concept. Tom proposes a new keyword because the concept *Task* has no keywords. He does so by selecting the option *Add Keyword* from the *Collaboration* menu (Figure 55). He introduces the concept name to which the keyword is proposed (*Task*), the name of the proposed keyword (*value*) and the corresponding rating (*0.6*). ViDESK displays a new voting window for the add keyword proposal as shown in Figure 73.

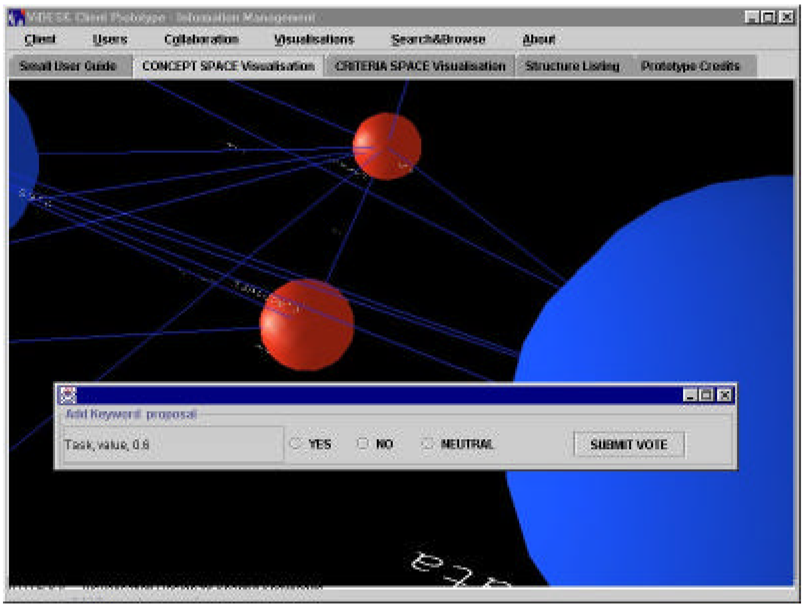

Figure 73: asking for a vote on the new keyword proposal

Again a voting pool takes place but this time Luis and Mary voted *no*, and John and Tom voted *yes*. Because the number of *yes* votes is not greater than half plus one of the group members – in this case, three – the proposal was not accepted. This results in the structure not being updated.

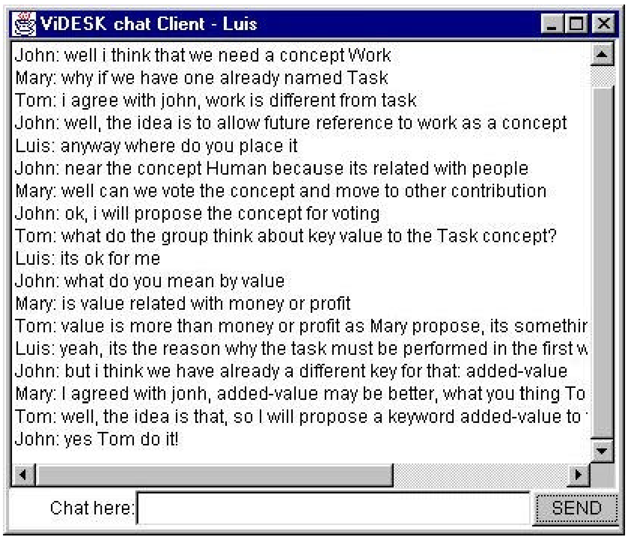

Figure 74: a chat window resulting from structure enhancing discussion

Figure 74 shows the use of the chat system during the structure enhancement discussion. The text from chat log is given in Figure 75 for the structure enhancing situations described above – the *add concept* proposal and the *add keyword* proposal.

(…)
Luis: please can John give info about prop
John: well I think that we need a concept Work
Mary: why, if we have one already named Task
Tom: I agree with john, work is different from task
John: well, the idea is to allow future reference to work as a concept
Luis: anyway where do you place it
John: near the concept Human because its related to people
Mary: well can we vote the concept and move to other contribution
John: ok, I will propose the concept for voting
Tom: what do the group think about key value to the Task concept?
Luis: it's ok for me
John: what do you mean by value
Mary: is it value related with money or profit
Tom: value is more than money or profit as Mary proposes, its something that results from doing the task
Luis: yeah, it's the reason why the task must be performed in the first way
John: but I think we already have a different key for that: added-value
Mary: I agreed with John, added-value may be better, what you think Tom?
Tom: well, the idea is that, so I will propose a keyword added-value to the task concept
John: yes Tom do it!
(…)

Figure 75: Text log for the structure enhancing discussion

FINAL REMARKS

Mary, Tom, Luis and John (the lecturer) can actively participate in the structure enhancement. The ViDESK system allows the interaction between group members and individually each member can relate the structure for knowledge sharing with a data source. This relation provides the means to integrate the context reported by the structure for sharing knowledge with available data. Additionally, each member can inform others about his/her own perspective and participate in the knowledge construction activity.

For John, as a lecturer, the system also produces useful information that can help him to refine initial structures for *Information Management*. The ViDESK system also provides knowledge about the student perspectives about *Information Management*.

6.5 Summary

The ViDESK prototype has been presented. It provides support for sharing the structure for knowledge sharing. It is an implementation of the two-part visualisation design and the information visualisation facility. A detailed description of the prototype from the user point of view has been provided. The ViDESK prototype used for evaluation implements the 3D interactive visualisation design and integrates with it a number of features for use in a collaborative learning environment:

1. a two-part visualisation design composed of a concept space and a criteria space;
2. a 3D interactive visualisation;
3. a network support;
4. a voting tool;
5. a chat system;
6. an Information Visualisation;
7. a simple browser;
8. a textual search engine;
9. an interface to input the knowledge structure.

Additionally, a user scenario has been provided to highlight how ViDESK can be used as a learning environment too. Taking also into account current CSCL systems, ViDESK has potential as a collaborative learning tool and provides a valid evaluation tool to assess the use of 3D interactive visualisations to support collaborative learning.

Chapter 7 – E**xperiments to evaluate the system in use**, describes the experimentation conducted to evaluate the ViDESK prototype presented in this chapter. Chapter 8 – **Experimental Results**, describes and analyses the data gathered.

7 Experiments to evaluate the system in use

7.1 Introduction

Addressing the research problem of how to share knowledge between a group of people engaged in learning activities, a visualisation for knowledge sharing, the ViDESK system, was developed. ViDESK supports collaborative learning by minimising cognitive overhead and information overload.

- to minimise cognitive overhead support was provided for user understanding, confidence and feedback;
- to minimise information overload support was provided to control the amount of information available to the user by providing representation facilities and customised detail.

The ViDESK implementation was presented in chapter 6 – **Implementing a knowledge sharing system**, providing a set of facilities: a two-part visualisation design; a 3D interactive visualisation; a network support; a voting tool; a chat system; an Information Visualisation; a simple browser; a textual search engine; and an interface to input the knowledge structure.

This chapter presents the evaluation of the ViDESK (*Visualisation Design for Sharing Knowledge*) model and its prototype implementation. The chapter describes the evaluation strategy and the experimental methodology used.

The thesis addresses the problem of how to share knowledge to support collaborative learning. It also asserts that the use of both the structure for knowledge sharing and the visualisation design can be used for knowledge sharing in the context of collaborative learning.

The work objectives are: (1) support of knowledge sharing for collaborative learning by (2) minimising cognitive overhead and (3) minimising information overload. Additionally, a number of experimental conclusions were considered, taking into account the resulting actions. These actions are: (1) easier user interaction; (2) providing a high abstraction level to describe a knowledge context; (3) supporting data source analysis, and (4) providing a context meta-description to analyse and compare different data sources. Table 3 summarises the work objectives and experimental conclusions.

Number	Description
	Work objectives
1	Support collaborative learning
2	Minimise cognitive overhead
3	Minimise information overload
	Experimental conclusions
1	Ease user interaction
2	Provide a high abstraction level to describe a knowledge context
3	Support data source analysis
4	Provide a context meta-description to analyse and compare different data sources

Table 3: Work objectives and experimental conclusions

The prototype was intended to test both the functionality and effectiveness of the use of the structure for knowledge sharing and the design of the visualisation to support collaborative learning.

The developed prototype implements the main ideas proposed by the ViDESK model:

- a (textual) structure for representing the knowledge to be shared;
- a visualisation design to convey information about the structure being shared;
- an environment to allow the use of the structure and visualisation design to discuss and collaboratively enhance the knowledge being shared.

The rest of this chapter is structured as follows:

- Section 7.2 – "Experiments", where experiments to evaluate ViDESK are introduced.
- Section 7.3 – "Using tasks to conduct the experiment", discusses the strategies used for the ViDESK evaluation.
- Section 7.4 – "Experimental methodology", describes the methodology used to conduct the ViDESK evaluation.
- Section 7.5 – "Experimental procedures", presents the precise procedures used to evaluate the ViDESK prototype.
- Section 7.6 – "Summary", summarises the chapter and briefly introduces the next chapter.

7.2 Experiments

To evaluate the extent to which ViDESK fulfils the specified work objectives, three distinct experiments were developed to test different issues related to the work objectives and experimental conclusions, allowing better data analysis and minimising data gathering complexity. Due to the multidisciplinary nature of this work, the evaluation assumes an important role, helping to analyse how the ViDESK prototype impacts each of the work objectives.

The following assumptions made in each experiment helped to conduct the experiments. The experimental results are used to inform each of the work objectives evaluation. The assumptions are important because they guide how both the work objectives and experimental conclusions can be confirmed regarding each experience set up.

EXPERIMENT 1

Experiment 1 considered experts developing a structure for knowledge sharing and specifying its visualisation. Four assumptions can be considered taking into account experiment 1:

1.1 it is possible to build a structure for knowledge sharing for a specific knowledge theme. By testing this assumption it is possible to help confirm the work objective of supporting collaborative learning, and also the experimental conclusion of providing a high abstraction level to describe a knowledge context;

1.2 it is possible for an expert to specify the visualisation parameters for the knowledge sharing structure. By testing this assumption it is possible to help confirm the experimental conclusion of providing a high abstraction level to describe a knowledge context;

1.3 experts consider the structure useful for their own knowledge view. By testing this assumption it is possible to help confirm both work objectives: minimise cognitive overhead and minimise information overload;

1.4 experts consider the visualisation as a better representation when compared to the textual description. By testing this assumption it is possible to help confirm both the work objective of minimising cognitive overhead and the experimental conclusion of ease user interaction.

Taking into account these assumptions and their relation with work objectives and experimental conclusions, experiment 1 focused on assessing how:

- a particular knowledge theme can be represented by the (textual) structure;
- the visualisation design can represent the structure;
- the ViDESK prototype can be used to create the structure.

EXPERIMENT 2

Experiment 2 considers exploring an existing structure by interacting with its visualisation. Four assumptions can be considered for experiment 2:

2.1 it is possible for users to obtain and use information conveyed by the visualisation design. By testing this assumption it is possible to help confirm two work objectives: minimising cognitive overhead, and minimising information overload, and also, the experimental conclusion of making ease user interaction;

2.2 it is possible for users to reason about and describe the structure of the knowledge theme being represented. By testing this assumption it is possible to help confirm the work objective of supporting collaborative learning, and also, the experimental conclusions of ease user interaction and providing a high abstraction level to describe a knowledge context;

2.3 it is possible for users to take advantage of the visualisation design to analyse the structure's relationships. By testing this assumption it is possible to help confirm the experimental conclusion of providing a high abstraction level to describe a knowledge context;

2.4 it is possible for users to compare the knowledge theme view with data source information that is provided by the visualisation design. By testing this assumption it is possible to help confirm the work objective of minimising information overload, and also, the experimental conclusions of supporting data source analysis and providing a context meta-description to analyse and compare different data sources.

Taking into account these assumptions and their relationship with work objectives and experimental conclusions, experiment 2 focused on assessing how:

- a user can understand the structure;
- a user can individually learn;
- a user can be supported for accessing a data source.

EXPERIMENT 3

Experiment 3 considers enhancements to the structure using the visualisation for shared interaction. Four assumptions can be considered taking into account:

3.1 it is possible to use the structure and visualisation design for knowledge sharing of a given knowledge theme; By testing this assumption it is possible to help confirm two work objectives: minimising cognitive overhead and supporting collaborative learning, and also, the experimental conclusion of providing a high abstraction level to describe a knowledge context;

3.2 it is possible to enhance the structure using the visualisation design as an interface. By testing this assumption it is possible to help confirm two work objectives: minimising information overload and supporting collaborative learning, and also, the experimental conclusion of ease user interaction;

3.3 it is possible to explore the structure's relationships using the visualisation design as an interface. By testing this assumption it is possible to help confirm two work objectives: minimising cognitive overhead and minimising information overload, and also, the experimental conclusion of ease user interaction;

3.4 it is possible to engage users in collaborative learning using the visualisation design for a given knowledge theme. By testing this assumption it is possible to help confirm the work objective of supporting collaborative learning.

Taking into account these assumptions and their relation with work objectives and experimental conclusions, experiment 3 focused on assessing how:

- the users can share the structure;
- the users can enhance the structure;
- the users can learn collaboratively;

EXPERIMENTAL ASSUMPTIONS AND WORK OBJECTIVES

Taking into account the above assumptions and the work objectives we can relate them to Table 4. Also considered are the experimental conclusions.

Concerning the work objective 1 (*support collaborative learning*), assumptions 1.1 and 2.2 although addressing individual learning, they are regarded here as requirements to support collaborative learning.

	Experiment 1 assumptions				**Experiment 2 assumptions**				**Experiment 3 assumptions**				**Number of related assumpt.**
	1.1	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**	**3.1**	**3.2**	**3.3**	**3.4**	
Work objectives													
1	X					X			X	X		X	5
2			X	X	X				X		X		5
3			X		X			X		X	X		5
Experimental conclusions													
1				X	X	X				X	X		5
2	X	X				X	X		X				5
3								X					1
4								X					1

Table 4: Work objectives, experimental conclusions and experiments assumptions

The work objectives were addressed with the same number of assumptions. The evaluation only addresses, at the same level of analysis, the first two of the additional experimental conclusions. The other experimental conclusions regarding the support of data source analysis were addressed only by one assumption, which indicates the need for further research to be conducted.

Section 7.3 describes the strategy used to conduct the experiments to evaluate the model, proposing an evaluation based on three experiments where user interaction with the system is guided by specifying precise tasks to be undertaken. The experimental methodology adopted for the evaluation of the ViDESK system is presented in section 7.4. Section 7.5 outlines the experimental procedures. The results and their discussion are presented in chapter 8 – **Experimental Results**.

7.3 Using tasks to conduct the experiment

A recent study recommends that virtual design environments are very useful to convey complex educational design concepts [Kalawasky, 2000]. This seems to confirm the educational potential of such systems, which include the ViDESK prototype.

However, using a 3D space as the basis for the visualisation design brings some, as yet, unsolved problems concerning both the user and the platform to test the system [Erickson, 1993; Hubbold et al., 1995; Ingram and Benford, 1995]:

- user disorientation, leading to user confusion and spatial unawareness;
- novelty of the user interface, which differs from current available systems;
- the need for the user to learn symbols and navigation tools;
- processing and response times;
- interface limitations on the prototype, lack of adequate peripherals;
- hardware limitations on the prototype, (e.g. input/output devices).

Instead of dealing with each of the above issues separately, a task approach was followed. A number of tasks were designed for conducting the experiments. This focused user interactions on the more important issues regarding the research objectives and allowed direct observation of user activity. Concerning the hardware issues, the evaluation focuses mainly on testing the ViDESK approach without concern for using the best interface possible or trying to optimise system response times. However the reported issues must be taken into consideration for the evaluation design.

To test the ViDESK approach a number of different experiments were conducted to evaluate different parts of the system. The use of three distinct experiments allows concentration on particular issues needing evaluation in order to assess how the system can be used to support user learning.

The three distinct experiments to be conducted are:

1. Ask people to construct a structure and its visualisation. This supports evaluation of how the structure can be used to present an expert's view regarding a knowledge theme, and be meaningful to others.

   People were asked to build a structure for knowledge sharing. The structure is based on concepts (sets of keywords with a given name composed of one or more words), keywords (a word) and keyword ratings (the rating can be a value between zero and one, with two decimal places). The structure describes the view of an expert or a group of experts on a particular knowledge theme; it provides the context to reason about a given domain or topic – tacit knowledge. Tacit knowledge is defined as the knowledge that is used as a tool to handle or improve what is in focus [Sveiby, 1994]. Other users can enhance the structure by proposing new concepts, keywords and altering existing keyword ratings.
2. Ask people to explore an existing structure by interacting with its visual representation. This supports evaluation of how the visualisation design can be used

to support user interaction with the structure for knowledge sharing and how users understand structure content. It also tests how the visualisation can convey information about the structure.

People were asked to explore a visualisation that represents a structure about a given knowledge area (*Information Management*). Two parts comprise the visualisation design: the concept space and the criteria space. The concept space visualisation is used as the shared view for representing the structure. It allows each user to interact with the structure representation where concepts have a fixed spatial position. The criteria space can be customised by the user and presents the structure concepts placed according to user input criteria. The criteria space allows the organisation of concepts into variable spatial positions according to the criteria used which can be keywords from the structure. The rating of each keyword in a given concept yields its co-ordinates for spatial positioning. The concept space visualisation is used to explore the structure by enabling analysis of conceptual relationships based on up to three keywords. The criteria space visualisation is used to relate concepts using up to three keywords, taking advantage of using a 3D co-ordinate system to allow the spatial reorganisation of the structure representation.

3. Ask people to enhance a structure using the visualisation for shared interaction. This allows evaluation of both how the structure and the visualisation design can be used to support user collaboration to discuss and augment knowledge being shared and how users learn from that (promoting one kind of learning called reflection [Norman, 1991]). The learning is organised as collaborative learning.

   People were asked to use the visualisation to collaboratively enhance the shared structure. Each user can explore the visualisations to take advantage of the existing structure to learn about the knowledge theme being represented. The 3D interactive visualisation can help user learning about the structure theme being represented. The visualisation helps user interaction and supports its contribution to enhance the structure and thus allows user participation in the structure construction. Each user has a chat and voting facility to interact with other users.

Taking into consideration that ViDESK was evaluated using three distinct experiments, a number of different tasks were developed.

EXPERIMENT TASKS

For the first experiment, a single task was considered. The task was to construct a structure to specify an expert's view on the knowledge he/she wanted to share with others. This allowed evaluation of how the structure could be used to describe context knowledge as an expert view. Table 5 summarises task 1.1.

Task 1.1	Construct a structure for knowledge sharing
Title	Build a structure that provides the expert's view of a particular knowledge theme view, suitable for an introduction to the domain or topic.
Description	The task requires each participant to develop his/her own structure for a given theme. The participants are asked to develop a general structure that can be used by a broad audience in a higher education context. The goal is to build a structure that includes the most important concepts related to the theme.

Table 5: Experiment 1 task

For the second experiment, two tasks were considered for dealing with the structure visualisation and with the structure content. For the task concerning the structure visualisation, a list of questions was organised for guiding the user when interacting with the prototype. It works in a similar way to a checklist regarding the interaction with available ViDESK features. The task concerning the structure content deals with questions related to content analysis and user ability to understand the existing structure by using the ViDESK prototype. It includes questions related to user ability to contribute to new concepts and keywords. This allows evaluation of the use of the visualisation design to convey information about the structure. Table 6 summarises the two experiment 2 tasks.

Task 2.1	Structure visualisation
Title	Explore the visualisation to identify the structure elements and its relationships.
Description	Each user has direct support when needed with the researcher guiding the activity for task completion. The user is free to spend the time he/she wants and to ask any questions. This task is used for introducing system facilities and associated concepts.
Task 2.2	Structure content
Title	Explore the visualisation design in order to know more about the context knowledge being represented and propose more structure elements.
Description	Each user has direct support, when needed, for using the system. However, the researcher simply reacts to user questions and waits for participants' responses. Gathered data results from participant responses and user activity observation.

Table 6: Experiment 2 tasks

For the third experiment, a different task was requested. The task is related with the enhancement of a structure by proposing new structure elements for voting (concepts, keywords and keyword ratings).

The experiment is run in two ways, one with an existing structure and the other with an empty structure. In each run, each user must contribute with a specified number of concepts and keywords and is allowed to alter existing keyword ratings. This allows evaluation of how the structure content can be shared among and enhanced by, different people, and if it can be used for knowledge sharing. Table 7 summarises task 3.1.

Task 3.1	Collaborative construction of a structure
Title	Participate in the enhancement of the structure being shared
Description	Participate in the structure construction by proposing concepts, keywords and keyword ratings to be included in the structure. Use the system facilities to discuss and vote the proposals. It is expected that each user can contribute with at least two concepts and five keywords to the common structure. Two different situations will be tested using an existing structure, and start with an empty structure.

Table 7: Experiment 3 task

The strategy of using tasks to guide user interaction in the system allows the focusing of the evaluation on user impact and operation. In particular the main goal of the three experiments is to determine whether or not the system can be used to support collaborative learning.

7.4 Experimental Methodology

Evaluation in educational systems requires a good amount of effort. Both quantitative and qualitative studies need to be conducted in order to deal with different variables that must be considered to test an educational system [Cohen et al., 2000].

The notion of the role of evaluation in increasing our understanding of educational innovations is not new and was defended by Parlett [Parlett, 1974]. The adopted evaluation strategy takes into account results of other studies in virtual learning environments [Britain and Liber, 1999], 3D virtual environments [Kalawsky, 2000] and visualisation systems [Swan et al., 1998].

The tools used included records of user activities, pre and post-experiment questionnaires, user observation and system logs. Also included were pre and post-tests to assess knowledge embedded in task checklists. These tools were developed following the guidelines proposed by several authors [Britain and Liber, 1999; Cohen et al., 2000].

However, evaluation of collaborative technology is best done through field evaluations because these can be used to assess social-psychological and anthropological effects of the technology [Grudin, 1988]. An attempt to analyse all the dimensions involved in ViDESK usage would have lead to a huge amount of gathered data, much of it irrelevant to the learning process.

Moreover, ethnography is an intrinsically descriptive task that resists formalisation and its methods rely on the study of people and their activities in their natural environment. The method relies on understanding the setting from the point of view of those involved in it [Jones, 1998]. Hughes and other assert that the aim of ethnography is to see activities as social actions, embedded within a socially organised domain and accomplished in and through the day-to-day activities of participants [Hughes et al., 1994].

An ethnographic application in system design described by Hughes and other as evaluative ethnography, where the study is undertaken to verify or validate a set of already formulated decisions [Hughes et al., 1994]. Crabtree and other provide an example of evaluative ethnography applied to virtual environments where the authors claim that the design of virtual environments involves a significant degree of novelty and requires explicit study of participants at very early stages of the project [Crabtree et al., 1999].

The evaluation of the ViDESK prototype must take into account its own novelty and its impact on first time users. As asserted by Calvey and other, users need time and practice to learn how to use and become experts to take advantage of a computer support tool [Calvey et al., 1997]. As expert users they can both take full advantage of the system and discover new functions and applications.

The resulting experimental data must be summarised both quantitatively and qualitatively. User activity patterns must be analysed (e.g. from video recordings). Video observation is also important, since responses to questionnaires could be biased (e.g. towards positive responses) rather than objective (accurate reflection of levels of contribution). These responses need to be compared with video evidence to check consistency. The data gathered from all the post-experiment questionnaires takes into consideration the positive response effect that is minimised by performing a data transformation from a five scale variable for rating like – dislike, to a two scale variable (dichotomise the variable). This transformation takes two of the scale values as positive (only one in experiment 2) and considers the other values as negative. A complete discussion of methods for data gathering using different strategies applied to educations is presented by Cohen, Manion and Morrison [Cohen et al., 2000].

For the first experiment, the system evaluation factors are pre and post-experiment questionnaires and analysis of resulting structures.

For the second and third experiments, system evaluation factors are pre and post-experiment questionnaires and observation of user activities during the tasks' completion. Some of the evaluation sessions were video recorded for later analysis of user actions, concerning the use of the ViDESK prototype.

A number of additional observations were also made during the three experiments and reported as empirical findings to complement gathered results. These observations result from detecting user interaction patterns, from user questions and from any unexpected situation that occured during the experiment.

The ViDESK evaluation was designed to assess how:

- a particular knowledge theme can be represented by the structure;
- the visualisation can represent the structure;
- the ViDESK prototype can be used to input the structure;
- users can understand the structure by exploring a visualisation composed of a concept space and a criteria space;
- users can share the structure by using the concept space visualisation as an interface;
- users can enhance the structure by using a voting tool and a chat system to collaborate based on information and impact in the visualisation;
- users can learn individually (related to the structure content) by exploring a visualisation composed of a concept space and a criteria space;
- users can learn collaboratively by exploring and participating in the structure enhancement;

- users can be supported in accessing a data source by using an Information Visualisation within the criteria space with results displayed using a simple browser.

The selected users for testing the system were university teachers and students. Additionally, a number of selected cases were included to analyse how young and mature people react to ViDESK. It is expected that users' learning can result both from using the ViDESK visualisation design and from collaboratively enhancing a structure for knowledge sharing.

The ViDESK prototype used for the evaluation implements the 3D interactive visualisation design and integrates with it a number of features for use in a collaborative learning environment, as already introduced in chapter 6:

1. a two-part visualisation design composed of a concept space and a criteria space;
2. a 3D interactive visualisation;
3. a network support;
4. a voting tool;
5. a chat system;
6. an Information Visualisation;
7. a simple browser;
8. a textual search engine;
9. an interface to input the knowledge structure.

For each of the three experiments and corresponding tasks, a different version of the prototype was used with a particular selection of the available prototype' features. This was done in order to ease both evaluation procedures and user operation. It has also enabled a decrease in the specification requirements for hardware and thus provided more mobility to perform evaluation sessions in different locations.

In experiment 1 paper and pencil was used by the structure experts to do the specification. A modified interface was used to optimise the structure input and its visualisation allowing the use of a function set for modifying the knowledge structure.

In experiment 2, a standalone version of the prototype was used with complete functionality except for networking, chat and the voting tool.

In experiment 3 the full system functionality was provided taking into account the need for each user to interact with others to perform the experimental task.

Table 8 summarises the prototype facilities used in each experiment.

	Prototype facilities								
Experiment/task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1 / 1.1	X	X							X
2 / 2.1 and 2.2	X	X				X	X	X	
3 / 3.1	X	X	X	X	X	X	X	X	

Table 8: Prototype facilities used by experiment

The prototype facilities 1 and 2 represent the visualisation design. Facilities 3, 4 and 5 the collaborative issues and facilities 6, 7 and 8 the integration with data sources. For the evaluation, the available hard disk information.

7.5 Experimental procedures

The pilot system was tested with volunteers from the Fernando Pessoa University, Portugal, using the developed prototype in English (as is the case for many other applications on the Windows platform). The pilot test was used to improve the wording in the prototype's interface and introduce a number of additional features to support navigation in the concept space, such as the refresh visualisation option, the orientation axis in the origin and a reduction of the relations shown between visible concepts. These features were described in detail in chapter 6, section 6.3.

As three experiments were conducted, the participants, evaluation scripts and physical environment must be described for each one apart. All the experiments took place in Portugal between May and July 2000 and used volunteers from *University Fernando Pessoa* and other local institutions in Porto, Portugal, considering the special cases of young and mature people. Although some cultural issues may apply, the use of tasks to conduct the experiment may help reduce its influence [Kalawsky, 2000].

The total time spent on evaluation exceeded 140 hours with 60 volunteers involved. These values do not take into account earlier trials and pilot testing that involved more evaluation hours and users. Volunteers agreed to participate in the evaluation sessions and no payment was made for their involvement.

7.5.1 Construct a structure and its visualisation

The first experiment is based on one task where an expert is asked to build a structure describing a particular knowledge theme in which he/she is expert. The evaluation focused on assessing how:

- a particular knowledge theme can be represented by the structure;
- the visualisation design can represent the structure;
- the ViDESK prototype can be used to create the structure;

PARTICIPANTS

Twelve participants were involved in experiment 1:

- six local experts on Information Management;
- the other six experts in different areas – knowledge themes (Dance, Bakery, Human Resources, Earth Sciences, Football, Mechatronics)

The chosen knowledge theme was *Information Management*. However, a number of additional themes were also considered to determine if the structure could be used to specify the experts' views.

The experiment consisted of the following activities, as summarised in Table 9:

- Participant completes a participant pre-experiment questionnaire (appendix B.1)
- Researcher introduces the system, with a demo, and provides an experiment goal description. To introduce the system and the experiment goal description, a live demo was presented of its main features. Following this, a standalone version of the ViDESK prototype was used to input the structure in a "hands-on" session involving the participants. Each participant was asked to perform a single task: construct a structure for knowledge sharing about his/her expertise theme. The participants were asked to construct their own structure about their theme. They were allowed 30 minutes reflection time for preparing their structure after a brief explanation of the system.
- With the help of the researcher, the participant inserted the structure into the system and was given a second system demonstration.
- The participant then completed a post-experiment questionnaire (appendix B.2).

Activity	Duration (mm)
Introduce the system and experiment goal description	5
Complete a participant pre experiment questionnaire	2
Introduce ViDESK concepts (including the structure elements)	15
General overview of the system functionality (prototype demo)	15
ask for the structure specification for the expert's theme	30
input the structure (with researcher support for system operation)	30
Explore the concept space visualisation	15
Complete a participant post-experiment questionnaire	8

Table 9: Experiment 1 evaluation script (completion time: 120 minutes)

PHYSICAL ENVIRONMENT

The structure construction test was conducted on a Compaq Armada 1573D Laptop with an additional external 3-button mouse. The laptop introduces some difficulties for the user interface concerning its display, but enables more mobility to apply the test when and where possible. The ViDESK prototype version used was a standalone version without network services in order to increase computer response times.

The test was always made with the computer on a table with daylight exposure in a room where only the participants and the researcher were present. The table had only the laptop and the evaluation materials on it.

Reported difficulties in using the laptop computer were related to the laptop monitor limitations. The computer had the following technical specifications: an Intel Pentium MMX at 233MHz processor, 64 Mb RAM, 3102 Mb IBM hard disk, a graphics card C&T 68554 PCI 2Mb used with a 800x600 resolution in a 12,1" stn passive display, a Portuguese keyboard, and an external 3-button mouse EasyMouse Genius. The operating system was Microsoft Windows 95 (Win95B build 4.00.1111).

7.5.2 Explore a structure by navigating the visualisation

The second experiment was based on two tasks in which each participant was asked to use the ViDESK prototype. The tasks were designed to allow the exploration of the visualisation both for testing the visualisation and structure content. The tasks followed a checklist to be accomplished. The experiment focused on assessing how:

- users can understand the structure;

- users can individually learn;
- users can be supported in accessing a data source;

PARTICIPANTS

A total of forty (40) participants were involved in experiment 2:

- a group of undergraduate students (10);
- a group of graduate students (11);
- a group of university staff (11);
- a small group of young people (4);
- a small group of mature people (4).

The first three groups were composed of members recruited from the Fernando Pessoa University and other local universities. The last two groups' members were recruited among personal contacts to fulfil the requirements for both young and mature people. Appendix C provides more detailed information about the characteristics of the group members ages, sex and instruction degree.

The experiment consisted of the following activities, as summarised in Table 10:

- Participant completes a pre-experiment questionnaire (appendix B.1).
- Researcher introduces the Information Management theme using a related paper and provides an experiment goal description. All the participants use a structure about the Information Management theme. This structure, presented in appendix A, is based on Wilson textbook [Wilson, 1997]. To introduce the theme a four page article was used: Butcher, D and Rowley, J. - The 7 R's of Information Management, Managing Information, March 1998 (vol 5, n. 2). The goal was to explore the structure for knowledge sharing (about the Information Management theme) and to perform two tasks concerning visualisation and content facilities.
- Participant uses the ViDESK prototype to perform two tasks: one about the structure visualisation (appendix B.3) and the other about structure content (appendix B.4)
- Participant completes a post-experiment questionnaire (appendix B.5).

Activity	Duration (mm)
introduce the system and experiment goal description	5
complete a participant pre-experiment questionnaire	2
introduce ViDESK concepts (including the structure elements)	10
general overview of the system functionality (prototype demo)	5
participant reads the article about *Information Management* (theme introduction)	30
lab training period	10
participant performs the two tasks (task 2.1 and task 2.2)	50
participant completes a post-experiment questionnaire	8

Table 10: Experiment 2 evaluation script (completion time: 120 minutes)

PHYSICAL ENVIRONMENT

The same computer specified for experiment 1 was used. The prototype includes the Information Visualisation, the browser and the search engine integration facilities, as reported in section 7.3.

Physical conditions were the same as experiment 1. Each test was repeated for each participant in turn. The total test time with experiment 1 exceeded 100 hours including set up times and participant test time extensions.

7.5.3 Enhance a structure by using the visualisation for shared interaction

The third experiment was based on the collaborative construction of a structure where a group of participants used the ViDESK prototype to construct and enhance a structure for knowledge sharing. Each participant had his/her own computer running ViDESK prototype and a computer network connected all the participants. The experiment focused on assessing how:

- users can share the structure
- users can enhance the structure
- users can learn collaboratively

PARTICIPANTS

A total of eight (8) participants were involved in experiment 3:

- two groups of four participants each, selected from the 42 participants from experiment 2.

The two groups were composed of subjects from experiment 2 because this would provide a previous introduction both to the ViDESK concepts and prototype usage. Appendix C.2 provides more information about the characteristics of the two group elements. Each group has a different set of activities because one of the groups uses the ViDESK prototype and the other uses direct communication between its members (with the help of paper and pen, and oral communication).

The learning outcomes from each experiment are different, according to different kinds of experience as individual exploration (experiment 2) and collaborative experience (experiment 3) engages participants in different contexts and complementary learning experiences as described in appendix C. Also, this way, participants in experiment 3 have already been introduced to ViDESK prototype.

The experiment consisted of the following activities, as summarised in Table 11:

- Participant completes a pre-experiment questionnaire (appendix B.1).
- Researcher provides an experiment goal description. The goal was to contribute to the creation and enhancement of a structure for knowledge sharing about Information Management, using the available facilities. The first group used paper and pen and oral communication with group members placed around a table. The second group used the ViDESK prototype; in this case, the researcher introduced the ViDESK prototype functionality.
- The participants were asked to use system facilities to perform a common task. The task had two phases: one for an existing structure about the theme and, following this, with an empty structure. Two knowledge themes were considered which means that the task was performed twice. The first time used a theme that could be easily understood by every participant (the chosen theme was Holidays – appendix B.6). The second time involved the Information Management theme (using a different structure from the one used in experiment 2 - appendix B.7). For each phase, participants followed the experiment 3, task 3.1 checklist (appendix B.8). All the participants had access to written material about the Information Management theme to help them propose and vote concepts and keywords to be included in the structure. The written material was composed of a 4 page article: Butcher, D and Rowley, J. - The 7 R's of Information Management, Managing Information, March 1998 (vol. 5, n. 2) and a more

detailed paper (20 pages): Choo, C. – Information Management for the Intelligent Organization: Roles and implications for the information professions. Digital Libraries Conference, March 27-28, 1995, Singapore.

- Participant completes a post-experiment questionnaire (appendix B.9).

Activity	Duration (mm)
introduce the system and experiment goal description	5
complete a participant pre-experiment questionnaire	2
introduce ViDESK concepts (including the structure elements)	10
general overview of the system functionality (demo for the second group)	10
participant performs the task (task 3.1)	60
participant completes a post-experiment questionnaire	8
repeat the evaluation script using the two themes: *Holidays* and *Information Management*	95

Table 11:Experiment 3 evaluation script (completion time: 190 minutes)

PHYSICAL ENVIRONMENT

The first group used a large table where the four group participants could be seated in positions where each participant could write without the others seeing what he/she was writing. The second group used the ViDESK prototype. The ViDESK prototype version used was a full-networked version with a set of services available for user support and collaboration (voting tool and a chat system) as reported in section 7.4 for experiment 3.

The test was performed in a room prepared for the test, with two computers on separate desks and the other two on a round table with the respective monitors in positions that did not allow a user to see both displays. Users were asked not to speak during the test.

The client computers have the following technical specifications: an Intel Pentium MMX at 233MHz processor, 32 Mb RAM, 2 GB hard disk, a graphics card S3 with an 800x600 resolution, a 15" SVGA monitor, a Portuguese keyboard, and a 3-buttom mouse. The operating system is Microsoft Windows 95 (Win95B build 4.00.950). The server computer was an Intel Pentium 133 MHz, 32 Mb RAM, 1,5 Gb hard drive, a graphics card S3 with an 800x600 resolution, a 14" SVGA monitor, a Portuguese keyboard, and a 3-button mouse. The server operating system was the Microsoft Windows NT 4.0 with service pack 3.0 (WinNT build 4.00.1381). A 3COM Office Connect Hub TP4 provides the network support. The total number of connected computers was three clients and the server, providing four simultaneous workstations in the networked version of the ViDESK prototype.

The total time for experiment 3 exceeded more than 20 hours including set up times and the two runs for each group.

7.6 Summary

This chapter has described how the ViDESK prototype was used to evaluate the ViDESK approach and assess how and to what extent users can share knowledge, particulary when engaged in learning activities together.

The design of the experiments followed a strategy based on specified tasks to be performed by users in a series of three experiments. Together, these experiments enable the testing of the system support for collaborative learning, minimising cognitive overhead and minimising information overload.

The three experiments were:

- first experiment: oriented to assess how an expert can use a structure for knowledge sharing to specify a knowledge theme, including the use of the concept space visualisation to represent it;
- second experiment: considers how a user can explore the knowledge theme taking advantage of the visualisation design and the ViDESK system;
- third experiment is focused on how the ViDESK system can be used to support collaborative learning by requiring a group to enhance a structure for knowledge sharing.

Chapter 8 – **Experimental Results** discusses and analyses the data gathered from the experiments described in this chapter.

8 Experimental results

8.1 Introduction

This chapter presents and analyses the results of the evaluation conducted with the ViDESK prototype. The ViDESK prototype intends to test both the functionality and the effectiveness of the use of the structure for knowledge sharing and the visualisation to support collaborative learning.

The research addresses the problem of how to share knowledge to support collaborative learning. The thesis claims that both the structure for knowledge sharing and the visualisation can be used for knowledge sharing in the context of collaborative learning.

The work objectives are:

- *supporting collaborative learning*: providing the means for a group of people to work together in learning activities, while allowing individual learning to take place. Sharing a common set of concepts is essential to involve each individual in group communication.
- *minimise cognitive overhead*: provide support to minimise user confusion or difficulties in making choices and decisions. Cognitive overhead quantifies demands made on working memory;
- *minimise information overload*: minimise the problem of a user receiving more information than he/she can process by providing a context in which to use information. Information overload occurs when the user's information processing capacity is exceeded.

Additionally, four experimental conclusions were also evaluated:

- *ease user interaction*, by providing a visualisation with which to explore the structure for knowledge sharing and allow the collaborative enhancement of the structure.
- *provide a high abstraction level to describe a knowledge context*, by using a network of concepts to describe a knowledge theme both having a high level description and a visual representation.
- *support data source analysis*, by using an information visualisation, integrating with a browser and search string generation, it is possible to relate the knowledge theme to real world data.

- *provide a context meta-description to analyse and compare different data sources*. This is made possible by having a visualisation that both represents the knowledge theme as a context description and information of a data source integrated as an information visualisation. By changing the data source, it is possible to use the same context and thus provide means of comparison between the context and different data sources.

The evaluation comprised a set of three experiments that were described in detail in chapter 7 – **Experiments to evaluate the system in use**. The need for three experiments to evaluate the research objectives arose in order to provide a structured approach to determining the extent to which the ViDESK system addresses the sharing knowledge to support collaborative learning and provide answers to how:

- a particular knowledge theme can be represented by the structure;
- the visualisation can represent the structure;
- the ViDESK prototype can be used to input the structure;
- users can understand the structure by exploring a visualisation composed of a concept space and a criteria space;
- users can share the structure by using the concept space visualisation as an interface;
- users can enhance the structure by using a voting tool and a chat system to collaborate and influence the form of the visualisation;
- users can learn individually (related to the structure content) by exploring a visualisation composed of a concept space and a criteria space;
- users can learn collaboratively by exploring and participating in the structure enhancement;
- users can be supported in accessing a data source by using an Information Visualisation within the criteria space with results being displayed in a simple browser window.

The three experiments were:

- **Experiment 1** focused on assessing how a particular knowledge theme can be represented by the structure, how the visualisation can represent the structure and how the ViDESK prototype can be used to create the structure.

To address these issues, experiment 1 was based on constructing a structure for knowledge sharing where each expert chooses the knowledge theme and specifies his/her view, including the visualisation and ViDESK structure.

The important aspects of this experiment are the resulting structures and the experts' opinions about the structure construction, the resulting structure and visualisation reported in the post-experiment questionnaire.

- **Experiment 2** focused on assessing how much a user understands the structure, how a user can individually learn from using the ViDESK system and how a user can be supported in accessing a data source.

To address these issues, experiment 2 was based on asking the user to explore the ViDESK prototype in performing two tasks. One task related to the structure visualisation to explore the visualisation and obtain information about the structure. The other task was related with the structure content - the knowledge theme itself. The two tasks included a number of requests designed to assess how the user could learn about the knowledge theme by using the system.

The important aspects of this experiment are the user responses to proposed tasks, and their opinions about the system support for navigation, content exploration and data source access reported in the post-experiment questionnaire.

Additional information from the experiment was provided by statistical analysis and ViDESK usage observation. In particular, a qualitative analysis of what users learned, based on the analysis of the users' contributions to the knowledge structure and their feedback performing the experiment 2 task.

- **Experiment 3** focused on determining how users share the structure, how users enhance the structure and how users learn collaboratively.

Experiment 3 was based on asking a group of four people to use the ViDESK prototype in a computer network, with each user operating his/her own ViDESK client. The group had the task of enhancing four structures about two knowledge themes. For each theme the users were asked to enhance an existing structure and, after that, populate an empty structure on the same theme.

The important aspects in this case are the users' resulting structures, the analysis of each user's contributions and their opinions about the system, what he/she thinks has been learned and respective reported justification. Users' opinions were collected using the post-experiment questionnaire. Observation of user interaction provided additional results for the experiment. Additionally, a qualitative analysis of users' interaction and chat logs inform the quality of learning that has been achieved.

All three experiments involved 60 volunteers and more than 140 evaluation hours. The reported results in this chapter represent only part of the available data and its organisation takes into account the evaluation questions presented in section 7.3 – Experimental Methodology. Empirical results were considered following on observation of ViDESK prototype usage, system logs and participants questions, remarks and proposals.

The experimental results are used to restate assumptions made in section 7.1, chapter 7 as described in detail in this chapter when the experiment results are analysed, and provide evidence for reflecting about the research objectives in section 9.1. – Objectives of the work re-visited.

Appendix C **– Experimental data**, presents in detail the results gathered from following the experimentation of ViDESK prototype, as reported in chapter 7. This appendix also reports qualitative detail of the experiments to inform the results discussion.

The rest of the chapter is structured as follows:

- Section 8.2 – "Analysis of experimental results", considers the ViDESK approach, the results of the experiments and further analysis. It provides a discussion of results against the ViDESK goals and the research issue of how to share knowledge between a group of people, in particular people engaged in collaborative learning.
- Section 8.3 – "Summary of experimental results", summarises the most important results obtained from the evaluation studies.

8.2 Analysis of experimental results

8.2.1 Experiment 1 data analysis

Results from experiment 1 are reported in Appendix C.1, where provided is detailed information about the participants' group characteristics, the resulting structures specified by the participants, the resulting visualisations for representing the structures, and the post-experiment questionnaire data.

Concerning expert opinions about how the concept space visualisation can be a useful representation for the structure and how experts can use the structure to make explicit their expertise in producing *Information Management* and other theme structures for knowledge sharing the following observations can be made:

- Experts tend to ask first what perspective they must provide before constructing the structure. They were asked to produce an introductory structure although it was intended to be complete enough to be used by other people.
- All the experts were able to produce a structure and although they were introduced to the system with a structure featuring 17 concepts they produced structures with a smaller number of concepts (between 5 and 10). They had a 30 minute time period to specify the structure as specified for the task in chapter 7.
- All the *Information Management* structures tend to have a similar number of concepts and associated keywords as already described but with very different concepts and relationships as a result of each of the user's interests.
- The resulting shapes of the structure visualisation are very different even for the same theme. This may indicate a flexibility to represent different perspectives by also allowing different "images" for each structure.
- Experts find the concept space visualisation helpful or very helpful.

Additionally, a study was conducted using statistical analysis methods. The post-experiment questionnaire (appendix B.2) questions were considered as study variables. The variable values were dichotomised from the questionnaire responses, grouping "very easy" and "easy" responses in one group and "neutral", "quite unhelpful", and "unhelpful" into another group.

Performing a non-parametric test – binomial – to compare the constructed structures with an analysis of computer and theme expertise against task opinions (construction, input and visualisation of the structure) the following observations can be made:

1. The structure construction task seems to be considered by the experts to be a nontrivial task, although they reported increasing degrees of difficulty in deriving the concepts, keywords, and keyword ratings, respectively.
2. The input structure task seems to be considered easy by experts at a confidence level of 5%.
3. The concept space visualisation seems to be considered informative by experts at a confidence level of 5%.
4. The resulting structures seem to be considered informative by experts at a confidence level of 5%.
5. A confidence level of 5% is the result of grouping as "positive" results two of the responses and as "negative", three of the five questionnaire alternatives. When not considered the neutral response as a "negative" one, the confidence level is 1%.

Performing a logistic regression for explaining computer expertise results based on the answers to the question of constructing the structure, inputting the structure, considering the visualisation as representative and structure informative the following observations can be made:

1. The computer expertise is approximately significant with a 10% level considering the opinion about the input structure task. This means that none of the participants responses showed a strong relation with computer expertise.
2. The computer expertise seems not to have any relation with expert's opinion on constructing the structure, considering the visualisation informative and considering the structure informative.

Performing a logistic regression for explaining theme expertise results based on the variables constructing the structure, inputting the structure, considering the visualisation informative and structure informative the following observations can be made:

1. The theme expertise is approximately significant with a 10% level considering the opinion about the input structure task, and opinion on how the structure could be informative. This means that none of the participants responses showed a strong relation with theme expertise.

2. The theme expertise seems not to have any relation with expert's opinion on constructing the structure and considering the visualisation informative.

From these results there seems to be some relation between computer expertise and prototype use for inputting the structure, and between computer expertise and theme expertise, when experts consider the visualisation informative. More important, there seems to be no influence from participants computer and theme expertise in their responses.

Qualitative details about experiment 1 and concerning the resulting structures for knowledge sharing and correspondent visualisations are fully described in appendix C.1

- **Reporting data from experiment 1: construct a structure and its visualisation.**

SUMMARY FOR EXPERIMENT 1

The following observations are made in the light of the experiment 1 results and the analysis of how the structure can be constructed and its ability to represent a structure for knowledge sharing. We also see how the system can be used to input the structure and how useful its concept space visualisation is.

- the structure can be useful for representing the view of an expert about a given theme. In order to present the knowledge theme a relatively small number of concepts are used (5 to 10). The constructed structure represents the expert's view and the participants' opinion was that the structure gives them the opportunity to express a valid theme relating to their expertise that can be shared. Overall, the participants found very helpful or helpful both the structure and its visualisation but they found the structure construction to be harder.
- the visualisation was considered helpful and was used as a representation for supporting the expert's discussion of his/her knowledge theme. In some cases, the visualisation was used to detect some improvements to be made and hidden relationships between concepts.
- Input of the structure for visualisation was considered very easy or easy. Just one expert responded that it was difficult (one that had little experience using computers). Some reported that the interface could better support input by displaying existing concepts and keywords and allow them to be selected for reuse. They also reported the need for a better way of indicating the concepts'

spatial position. The concept space visualisation was considered helpful and was used as a support to spatially place the concepts.

8.2.2 Experiment 2 data analysis

Results from experiment 2 are reported in Appendix C.2, where provided is detailed information about the participant group characteristics, the resulting data from participants' use of the structure visualisation, the resulting data from participants' exploration of the structure content, and the post-experiment questionnaire data.

Concerning the participants' opinions a number of statistical analysis methods were used to process experiment 2 results. Participants' opinions were expressed about the structure for knowledge sharing, and the visualisation, the system access to supporting data sources and whether or not the visualisation helps in understanding the structure.

The post-experiment questionnaire (appendix B.5) questions were considered as study variables. Performing a descriptive statistics test for the six post-experiment questionnaire questions results in Table 12, showing a majority of positive and very positive answers from the 40 test participants. Note that for the first question the number of participants was just 39 because one of the participants did not answer the question.

	Participants answers	Minimum value	Maximum value	Mean	Standard deviation
Rate the structure for Information Management	39	1	2	1,46	0,51
Rate concept space visualisation for exploring the structure	40	1	5	1,55	0,88
Rate criteria space visualisation for relating concepts	40	1	4	1,60	0,74
Rate support for accessing data	40	1	3	1,28	0,51
Rate system use to learn about Information Management	40	1	3	1,55	0,60
Rate the system for supporting users' own contributions to the structure	40	1	3	1,52	0,68

Table 12: Responses to the post-experiment 2 questionnaire

These values suggest a high level of participants' acceptance of the ViDESK prototype, both of its use and of its structure for knowledge sharing and visualisation.

The answers from the post-experiment questionnaire questions were dichotomised by identifying two groups: one with the "very helpful" answers and the other with the "quite helpful", "neutral", "quite unhelpful", and "unhelpful" answers, in order to process these data using statistical methods. The goal is to compare the post-experiment questionnaire questions against computer use and theme expertise, these being two variables associated with participants in the pre-experiment questionnaire (appendix B.1).

Performing a logistic regression to explain computer expertise results, based on the variables corresponding to the post-experiment questionnaire (structure for describing the theme, concept space visualisation for exploration, criteria space for relating, system support for access to a data source, system use for learning, and system support for user contributions) the following observations can be made:

1. The computer expertise is significant at a 1% level with respect to users' opinion that the system supports learning.
2. The computer expertise seems not to have any relationship with participant's opinions about the structure for describing the theme, concept space visualisation for exploring, and criteria space for relating, system support for accessing a data source, and system support for user contribution.

Performing a logistic regression to explaining theme expertise results, based on the variables that correspond to the post-experiment questionnaire the following observations can be made:

1. The theme expertise is significant at a 5% level with respect to the concept space visualisation for exploring the structure opinion.
2. The theme expertise is significant at a 5% level with respect to the criteria space visualisation for relating the structure opinion.
3. The theme expertise is significant at a 10% level with respect to the system support to access a data source opinion.
4. The theme expertise is approximately significant at a 10% level with respect to the structure for describing the theme opinion.
5. The theme expertise does not seem to have any relation to participant's opinion on system use for learning, and system support for user contribution.

The confidence level of 5% results from considering as positive answer only the "very helpful" option, again the other four options considered as negative. The confidence level changes to 1% if we considered the first to options ("very helpful" and "quite helpful" as positive). From these results there seems to be a relationship between what a participant could learn with the system and the computer expertise, and between the use of both visualisations and theme expertise.

These two relationships seem to show that if the user has some computer expertise he/she can learn more using the system, and if the user has some theme expertise he/she can better take advantage of the visualisations. Learning has been assessed using the tasks and analysing participants' responses to the experiment 2 task 2.1 checklist (appendix B.3).

Performing a logistic regression to compare the opinion about the learning effects from the post-experiment questionnaire with computer and theme expertise allows the following observations:

1. System support for learning about the theme in participant's opinions is significant at 1% level with respect to the computer expertise.
2. System support for learning about the theme, in the participant's opinion, seems not to have any significant relation to theme expertise.

Performing a logistic regression to compare the learning opinion from the post-experiment questionnaire with the other variables from the questionnaire allows the following observations:

1. System support for learning about the theme in participant's opinions is significant with a 1% level considering the opinion about the structure describing the *Information Management* theme.
2. System support for learning about the theme in participant's opinions seems not to have any significant relation to the other questionnaire variables (both visualisations, the data source access and structure contribution).

Performing a logistic regression to compare the opinion on system support to contribute with new concepts and keywords to the structure from the post-experiment questionnaire with the other variables from the questionnaire allows the following observations:

1. System support for accessing a data source in participant's opinions is significant at a 5% level considering the opinion about the structure describing the *Information Management* theme.
2. System support for accessing a data source in participant's opinions seems not to have any significant relation to the other questionnaire variables (both visualisations, the system use for learning and the contribution of the structure.

The relationship between the system use for learning and computer expertise was confirmed as was also the importance of the structure in describing the *Information Management* theme. Also, the structure for knowledge sharing was considered significant when related to the participant's opinions about the system for support structure contributions.

Qualitative details about experiment 2 and concerning the use of ViDESK prototype and the learning outcomes are described in appendix C.2 – **Reporting data from experiment 2: explore a structure by navigating the visualisation**.

SUMMARY FOR EXPERIMENT 2

A number of observations can be made taking into account the experiment 2 data resulting from ViDESK prototype usage and analysis:

- how people react to visualisation design;
- how participants complete the experiment tasks;
- how people understand the structure for knowledge sharing and use it as a tool for thinking (and learning) about *Information Management*.

The resulting experiment 2 observations are:

- Participants were able to contribute with new concepts and keywords related to the existing structure which seems to show that they were able to understand the *Information Management* structure. However, considering the use of the criteria space visualisation, when asked to describe a particular relationship between concepts in the structure, just 18 out 40 were able to give proper answers. The 18 participants who provided an answer had used the concept space visualisation as the major resource to support their answers, followed by reasoning about the structure content and, ultimately, using the criteria space visualisation. This seems to support the use of the concept space visualisation for representing the structure but raises the question of what use the criteria space is.

- In participant's opinions, they learn about the *Information Management* theme from using the ViDESK prototype. In fact, all the participants were able to contribute with new concepts to the existing structure (31 participants with two new concepts, and 9 just with one), with three keywords for the new concepts (all the 40 participants), and rate these keywords (33 out of 40 participants). Overall participants were able to contribute to the *Information Management* structure independently of their theme expertise, which may indicate that participants were able to learn about the *Information Management* theme. Note that just valid contributions, taking into consideration the context, were considered.
- One of the more popular ViDESK prototype facilities was the search engine browser. When asked to rate the prototype support for accessing data, most of the participants answered it was a very helpful facility (23 out 40 participants), and helpful (13 out 40). Several participants want to use the system to access the World Wide Web for their expertise areas proposing that they create the structure to test the prototype in their interest areas. In task 2.2, all the participants were able to make a concept search and choose a document related to the *Information Management* theme, which may indicate that the ViDESK prototype can support accessing data. However the information visualisation facility, integrated within the criteria space was just used by 4 participants. Further evaluation is needed to draw some conclusions about the information visualisation utility.

Additionally the following remarks can be made based on statistical treatment of gathered data:

- It seems to be possible to use the structure for knowledge sharing for describing at least the *Information Management* theme, providing participants with a context that they can explore and relate.
- Computer user expertise seems to be related to participant’s opinions on system support for learning.
- Theme expertise seems to be related to the participant’s ability to use both visualisations (concept space and criteria space visualisation).

From observation of the ViDESK usage the following observations can be made:

- The concept space visualisation seems to encourage participants to understand the structure concepts as it was used to complete the required tasks in the experiment.
- Users considered the criteria space visualisation more user-friendly and understandable. However the young group seems to have difficulties using it. Participants also reported that the criteria space visualisation produce *"more beautiful images*". Some participants reported that they easily understood the criteria space visualisation because they were able to *"fit it on the computer screen"*.
- The use of the navigation options seems to be easily learned by all the participants that were able to navigate both visualisations even considering the use of a laptop with a 12.1" STN display and an external 3-button mouse. Some participants report that using the ViDESK prototype is "*…fun and different from using computers in day to day tasks…*".

8.2.3 Experiment 3 data analysis

Results from experiment 3 are reported in Appendix C.3, where provided is detailed information about the participant group characteristics, the structures resulting from collaboration between group members, the paper and pen and ViDESK prototype support for collaboration, and the post-experiment questionnaire data.

This section analyses experiment 3 results by studying how the task was performed and how successfully was both paper and pen and ViDESK prototype use based on participants' opinions and considering experts evaluation of the resulting structures.

Based on the final structures resulting from performing task 3.1 for two themes and the two groups, 8 structures were obtained. Five *Information Management* experts rated these structures for knowledge sharing using a like/dislike scale. A final overall structure rating was calculated making an average of the three central values (not considering the higher and lower expert rates). The same experts were also asked to rate the structures about the *Holidays* theme. The structures were evaluated based on a printed description of the structure with the concepts, keywords and keyword rates.

Table 13 summarises the structure evaluation by the five experts. The helpful / unhelpful scale used was 1 – *"very helpful"*, 2 – *"helpful"*, 3 – *"neutral"*, 4 – *"quite unhelpful"*, 5 – *"unhelpful"*.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Overall score
Manual group						
Holidays, existent structure	2	2	4	3	2	2,33
Holidays, empty structure	3	2	3	3	2	2,66
Information Management, existent structure	2	1	2	1	2	1,66
Information Management, empty structure	2	4	3	3	2	2,66
System group						
Holidays, existent structure	2	3	2	2	3	2,33
Holidays, empty structure	2	2	1	2	2	2,00
Information Management, existent structure	2	1	2	2	1	1,66
Information Management, empty structure	3	2	2	1	3	2,33

Table 13: Structure evaluation by a panel of five *Information Management* experts

Some observations can be made based on the structure evaluation overall score:

- The overall score for all the structures were between a helpful and neutral evaluation being in most cases more close to the helpful score (2.00).
- The "starting with empty structures" situation tends to present a greater overall score which means that these situations tend to result in better structures for knowledge sharing when compared with starting task 3.1 with existing structures.
- Within the empty structures, just the system group structures had been evaluated as very helpful by one of the experts, in both themes.
- The system group has the same overall scores for the existing structures when compared with the manual group.
- The system group tends to have better evaluation overall scores for the empty structures when compared to the same structures from the manual group.

Taking into consideration what participants reported they learned, it is possible to summarise as follows:

- Participants from the manual group report for the *Holiday* theme that all had learned (4 out of 4). The following remarks provided qualitative detail to support the existence of learning episodes: one of the participants reported "*some of the discussed concepts were novel and allowed me to think of new perspectives*".

Another participant says "*I learn to «see» new concepts in a different perspective as well their role in constructed structure*". Two other participants report more general comments to justify their learning: "*I learned and made some discoveries about Holidays (…) The use of the structure was very positive and interesting (…) and allows mental development.*" and "*(…) the collaborative construction of the structure increases both confidence and security in learning new concepts. (…) It also allows students «rich» perspectives of the knowledge theme.*"

- Participants from the manual group for the *Information Management* theme report that they learned (3 out 4 participants): *"(…) there was information exchange that otherwise would not have been possible"*. Another participant reports, *"It was somewhat messy in the beginning but discussion allowed us to help each other"*. Other participants who reported to have learned commented that *"(…) as an expert I was able to observe others' difficulties because they have less knowledge about the theme.*"
- Participants from the system group report for the *Holiday* theme that they learn (3 out 4). One of the participants says, *"I learn that we are all different but can share some common ideas"*. Other participants add, *"(...) it was interesting but also a little frustrating that some of my proposals were not accepted. (…) Overall I like the sharing of the same image of the structure by all participants and I use it for discussion"*. One more participant refers that *"I learned a lot about other peoples' perspectives about Holidays. These perspectives complement mine and allow me to think of things that I would never remember to think".*
- Participants from the system group report they learn about *Information Management* (3 out 4 participants). One of the participants says, "*the concept space allowed me to think about the most important aspects of the structure*". Another participant says that "*I learned that even without knowing too much about Information Management, I was able to understand, contribute and discuss the structure - pretty cool!*" A last participant refers that "*I think that the most important thing I learnt was others' perspectives and the impact of new concepts and keywords on structure relationships. (…) Another learning issue was the possibility to discuss and create common meanings for concepts*". A participant that reported that no learning took place stated: *"(…) getting*

confused with the system (…) particular with what I think of each concept and what others say in discussion. The concept space just increases my confusion".

Based on the gathered participants justifications for what they learned performing task 3.1, it is possible to indicate that the enhancement of the structure for knowledge sharing provides learning opportunities. In particular, group discussion and voting seems to augment learning and to be more effective when using the ViDESK prototype. In this case, the system group was able to involve the group participants in the construction of the structure for knowledge sharing as further described in appendix C.3.

Additionally, a study can be done analysing the post-experiment questionnaire answers, by grouping results taking into account two variations for each question. The first option is to group for each question the values 1 and 2 as group A, and the values 3, 4, and 5 as group B; this indicates that the answers of very helpful and helpful were separated from the answers neutral, quite unhelpful, very unhelpful. The second option is to group for each question the value 1 as group A, and the other values, 2, 3, 4, and 5 as group B; meaning that what was not answered as very helpful was not from group A. These separation ranges also takes into account the number of reduced participants as was the case for experiment 1. Note that experiment 2 has a different separation range resulting from having a higher number of participants. Table 14 summarises each grouping occurrence for the two options considering the post-experiment questionnaire from experiment 3 (appendix B9).

Experiment 3 post-experiment questionnaire questions	**Manual group option 1**	**System group option 1**	**Manual group option 2**	**System group option 2**
1- understand others	7 - 1	6 – 2	1 – 7	4 - 4
2 - contribute to the structure	7 - 1	5 – 3	3 – 5	1 - 7
3- contribute to structure, compared with others	6 - 2	5 – 3	1 – 7	1 - 7
4 – task of constructing the common structure	7 - 1	5 – 3	2 –6	3 - 5
5 - opinion about the tool	7 - 1	5 – 3	1 – 7	0 - 8
6 - rate resulting structure	7 - 1	6 -2	1 – 7	2 - 6
7 - system/tool use		7 – 1		1 - 7
8 – concept space vis for exploring the structure		7 – 1		4 - 4
9 criteria space vis for exploring the structure		9 – 0		2 - 6
10 - rate the information vis for analyse/access data		5 – 3		1 - 7
11 – rate the 3D interactive vis in the system		6 – 2		4 - 4
12 – communicate with other participants	6 - 2	6 – 2	4 – 4	1 - 7
13 - learn about the theme	7 -1	6 – 2	7 – 1	6 - 2

Table 14: Grouping answers in experiment 3 post-experiment questionnaire

Based on the above table, the following observations can be made:

- the manual group presents more group A answers for all questions when considering option 1. This seems to confirm that paper and pen may have a more traditional interface for supporting structure collaboration as proposed by task 3.1.
- in questions related to the ViDESK prototype only (questions 7, 8, 9, 10, and 11) the number of group A answers were similar to the ones gathered for the manual group. This seems to indicate that participants have some difficulties using the system.
- considering option 2 values and comparing the manual group with the system group questions it seems possible to find three questions where system group answers were more positive. They are question 1 (understand what the other participants were communicating); question 4 (rate the task of creating the common structure), and question 6 (rate the resulting structure). This may indicate that although overall answers were worse for the system group, it suggests some indicators of better support for collaboration when compared to manual group answers. These results may need further research to be confirmed.
- considering the related ViDESK questions (7, 8, 9, 10, and 11) from system group, for option 2 it seems that questions 8 and 11 yield higher group A responses. This may indicate that the system group participants find the concept space visualisation very useful for exploring the structure and also rate the 3D interactive visualisation as very helpful.

Qualitative details about experiment 3 and concerning the structures resulting from collaboration between group members and evidence of supporting collaboration and collaborative learning are described in appendix C.3 – **Reporting data from experiment 3: enhance a structure by using the visualisation for shared interaction**.

SUMMARY FOR EXPERIMENT 3

A number of observations can be made taken on the basis of experiment 3 data resulting from both paper and pen (manual) and ViDESK prototype usage (system), and the experimental task:

- how people were able to enhance and share the structure for knowledge sharing

- use of the ViDESK prototype as a tool for collaborative learning.

The resulting experiment 3 observations are:

- sharing the structure for knowledge sharing took place in both groups. The manual group used paper and pen for note taking and voice communication for proposing, voting, and for discussion. The participants from the manual group were able to share the structure using paper and pen although some problems occur in updating ongoing enhancements to the structure. In the system group, participants were able to share the structure by using the concept space visualisation as an interface that allows each user to have access to the current version of the structure. The concept space visualisation was used most of the time to support voting and discussions. From the structure results it is possible to say that the concept space visualisation has served as an interface for participants sharing the structure with some advantages when compared to the paper and pen version: automatic updated and tracking relationships between concepts.
- enhance the structure for knowledge sharing. Both the paper and pen participants from the manual group and the ViDESK prototype participants from the system group seem to be able to propose, discuss and vote structure enhancements. The ViDESK prototype seems to support participant's actions to enhance the structure by providing a chat system and a voting tool integrated with the visualisation design. Participants from the system group were able to discuss more and make more rejections than the participants from the manual group, although they were able to make five times more contributions based on alter keyword rate actions. This seems to indicate that the system group has a more focused and productive structure enhancement than the manual group.
- learn with each other. Overall, in the participants' opinion each one was able to learn about both structure themes as reported by 13 of the 16 participants. Participants comments about performing task 3.1 seems to indicate that overall they had a good experience that was considered useful and allowed participants to learn about the knowledge theme being shared. The structures were enhanced with proper and acceptable new concepts and keywords and also by introducing new keywords for existing concepts (providing different concept relationships). All the participants were able to contribute with, at least, proposals for voting

and be involved in the discussion of others' proposals. The system group was able to use the visualisation design to explore the structure for knowledge sharing and based their collaborative actions (proposing, voting and discussion) on information taken from the visualisation design.

Additionally the following remarks can be made based on participants' observations:

- paper and pen use (manual group) provides a higher number of contributions to the structure for knowledge sharing (both concepts and keywords) but denotes more difficulty in getting a general updated perspective of the structure for knowledge sharing when compared to the use of the ViDESK prototype for the same goal. It also lacks support for concept relationship analysis in the structure for knowledge sharing.
- the ViDESK prototype (system group) provides more discussion between participants when compared with the manual group. The ViDESK prototype also provides better support for analysing the structure (in particular, its relationships) but it demands more time to be effective and requires that participants have some computer expertise to use the system.

8.3 Summary of experimental results

Taking into account the work objectives, the proposed experimental conclusions and the experimental results, it is possible to analyse how each objective was accomplished regarding the evaluation results. The discussion is conducted according to the established relation between assumptions and work objectives and between assumptions and experimental conclusions, as presented in section 7.1, from chapter 7 – **Experiments to evaluate the system in use**, and summarises the evaluation findings.

8.3.1 Work objectives analysis

WORK OBJECTIVE 1: SUPPORT COLLABORATIVE LEARNING

Collaborative learning is defined as groups working together for a common purpose, where individuals learn from being involved. Reported difficulties are the need for sharing a common ground of concepts and maintaining each individual communication within the group.

Related assumptions are:
(1.1) – it is possible to build a structure for knowledge sharing for a specific knowledge theme.
(2.2) – it is possible for users to reason about and describe the structure's content regarding the knowledge theme being represented.
(3.1) – it is possible to use the structure and visualisation for knowledge sharing of a given knowledge theme.
(3.2) – it is possible to enhance the structure using the visualisation as an interface.
(3.4) – it is possible to engage users collaborative learning using the visualisation for a given knowledge theme.

Based on these assumptions and on the experimentation results, the following conclusions can be made:

- regarding assumption 1.1, experiment 1 results show that the constructed structure presents the expert's view and participants opinions, and that the structure gives them the opportunity to express a valid context, that can be shared about a theme of their expertise.
- regarding assumption 2.2, experiment 2 results show that half of the participants were able to use the concept space visualisation as the major resource to support their answers, followed by reasoning about the structure content and, secondly, using the criteria space visualisation. However all the participants were able to contribute to the structure independently of their theme expertise.
- regarding assumption 3.1, experiment 3 results show that using the structure for knowledge sharing has been possible. Participants were able to discuss the structure content among group members, and some evidence was collected that each user reasoned about the knowledge theme being shared.
- regarding assumption 3.2, experiment 3 results show that participants were able to propose, discuss and vote on the structure enhancements. Participants using the ViDESK prototype were able to discuss more and make more rejections when compared to the paper and pen use, as reported in detail in appendix C. This seems to indicate that using the ViDESK prototype provides a more focused and productive structure enhancement when compared to the paper and pen use.

- regarding assumption 3.4, experiment 3 results show that most of the participants think they have learned from the knowledge theme views presented to them. Participants also report to have a good experience, which they considered useful, allowing them to learn about the knowledge theme being shared. All the participants enhanced the structures with proper and acceptable contributions.

Overall, the three experiments show the potential of using ViDESK ideas to support collaborative learning in a higher education context. Although current experimental results show that participants perform best if they have some experience of using computers and previous knowledge of the theme being discussed, all report that they learn from using the ViDESK prototype and being able to both discuss and make contributions to the structure for knowledge sharing.

WORK OBJECTIVE 2: MINIMISE COGNITIVE OVERHEAD

Cognitive overhead concerns the problem of a user becoming confused or having difficulty in making decisions. To minimise this, support must be provided to the user.

Related assumptions are:
(1.3) – experts consider the structure useful for their own knowledge view.
(1.4) – experts consider the visualisation as a better representation when compared with the textual description.
(2.1) – it is possible for users to obtain and use information conveyed by the visualisation.
(3.1) – it is possible to use the structure and visualisation for knowledge sharing of a given knowledge theme.
(3.3) – it is possible to explore the structure relationships using the visualisation as an interface.

Based on these assumptions and on experimental results, the following conclusions can be made:

- regarding assumption 1.3, experiment 1 results show that experts consider the use of a structure as a valid tool for representing their knowledge theme and that its use can provide a structured approach to this knowledge.

- regarding assumption 1.4, experiment 1 results show that most of the experts consider the 3D interactive visualisation useful when compared to the textual structure representation of the knowledge theme.
- regarding assumption 2.1, experiment 2 results show that participants were able to contribute with new concepts and keywords related to the existing structure which seems to show that they were able to understand the information conveyed by the structure. However, when asked to describe a particular relationship between concepts in the structure, less than half of the participants were able to give proper answers.
- assumption 3.1, was discussed under work objective 1.
- regarding assumption 3.3, experiment 3 results show that participants were able to share the structure by using the 3D interactive visualisation as an interface. Participants use the visualisation facility mostly to support their voting and discussion actions. Experiment 3 also shows that ViDESK use provokes more discussion between participants when compared to the paper and pen use. The ViDESK prototype also provides better support for analysing the structure (in particular, its relationships as reported in appendix C.3). However it demands more time to be effective and requires that participants must have some computer expertise to use the system.

Overall, the use of the ViDESK representations make it possible to minimise cognitive overhead by providing a direct manipulation 3D interactive visualisation where each participant can control, explore and manipulate a visual representation of the structure for knowledge sharing. This visualisation allows multiple perspectives and the discovery of structure relationships both on concepts and their contents (keywords), although some participants report difficulties using the visualisation because they feel somewhat lost using the 3D interactive visualisation.

WORK OBJECTIVE 3: MINIMISE INFORMATION OVERLOAD

Information overload concerns the problem of a user receiving more information than he/she can cope with. It occurs when the user's information processing capacity is exceeded.

Related assumptions are:

(1.3) – experts consider the structure useful for their own knowledge view.

(2.1) – it is possible for users to obtain and use information conveyed by the visualisation.

(2.4) – it is possible for users to compare the knowledge theme with data source information provided by the visualisation.

(3.2) – it is possible to enhance the structure using the visualisation as an interface.

(3.3) – it is possible to explore the structure relationships using the visualisation as an interface.

Based on these assumptions and on experimental results, the following conclusions can be made:

- assumption 1.3 was discussed under work objective 2.
- assumption 2.1 was discussed under work objective 2.
- regarding assumption 2.4, experiment 2 results show that participants consider the prototype support for accessing data very helpful or helpful. All the participants were able to make a concept search and choose a document related to the structure theme. However the information visualisation facility was only used by a small number of participants.
- assumption 3.2 was discussed under work objective 1.
- assumption 3.3 was discussed under work objective 2.

Overall, the ViDESK prototype was able to minimise information overload by offering a tool for the participants' individual exploration and group sharing of the structure for knowledge sharing. The tool allows exploring structural relationships and accommodating the existence of multiple alternative views of the structure. It also allows the construction of alternative visualisations to satisfy specific information needs. Although participants where able to use the tool, results show that a small number of participants will benefit from having a global view with all the existing structure elements *"fit on the screen"* with a current position/perspective tracing facility.

8.3.2 Experimental conclusions analysis

EXPERIMENTAL CONCLUSION 1: EASE USER INTERACTION

User interaction involves the user' related both with other users and with information artefacts as is the case of the ViDESK prototype. User interaction problems include difficulties in accomplishing required tasks and learning how to use and take advantage of available tools.

Related assumptions are:
(1.4) – experts consider the visualisation as a better representation when compared with the textual description.
(2.1) – it is possible for users to obtain and use information conveyed by the visualisation.
(2.2) – it is possible for users to reason about and describe the structure content regarding the knowledge theme being represented.
(3.2) – it is possible to enhance the structure using the visualisation as an interface.
(3.3) – it is possible to explore the structural relationships using the visualisation as an interface.

Based on these assumptions and on experimental results, the following conclusions can be made:

- assumption 1.4 was discussed under work objective 2.
- assumption 2.1 was discussed under work objective 2.
- assumption 2.2 was discussed under work objective 1.
- assumption 3.2 was discussed under work objective 1.
- assumption 3.3 was discussed under work objective 2.

Overall, the 3D interactive visualisation provides an interface for participant discussion and enhancement of the structure for knowledge sharing. The experimental results show that the visualisation design supports participant interaction within the group by proposing an "image" to convey knowledge to be shared among group elements. It also supports user interaction with the tool, though observation of users reveals a need for complementary support such as traditional text based tools (like the chat tool) for interaction between participants and also a need for textual structure listings for participant exploration of the structure for knowledge sharing.

EXPERIMENTAL CONCLUSION 2: PROVIDE A HIGH ABSTRACTION LEVEL TO DESCRIBE A KNOWLEDGE CONTEXT

This refers to a high level description for use by collaborative learners, to discuss models, conceptual relationships and to confront perspectives about a given knowledge theme.

Related assumptions are:
(1.1) – it is possible to build a structure for knowledge sharing for a specific knowledge theme.
(1.2) – it is possible for an expert to specify the visualisation parameters for the knowledge sharing structure.
(2.2) – it is possible for users to reason about and describe the structure content regarding the knowledge theme being represented.
(2.3) – it is possible for users to take advantage of the visualisation to analyse structure relationships.
(3.1) – it is possible to use the structure and visualisation for knowledge sharing of a given knowledge theme.

Based on these assumptions and on experimental results, the following conclusions can be made:

- assumption 1.1 was discussed under work objective 1.
- regarding assumption 1.2, experiment 1 results show that the visualisation was considered helpful and was used as a representation for supporting an expert's view of his/her knowledge theme. Experts were able to specify the visualisation parameters for the 3D interactive visualisation.
- assumption 2.2 was discussed under work objective 1.
- regarding assumption 2.3, experiment 2 results show that participants intensively use the 3D interactive visualisation to obtain information about the relationships between structure elements. However just half of the participants were able to take full advantage of ViDESK facilities to complete all the required tasks related to analysis of the structural relationships.
- assumption 3.1 was discussed under work objective 1.

Overall, experiment results show that participants were able to reason about the knowledge theme represented by the structure for knowledge sharing and the 3D interactive visualisation. As this structure provides a high level description for a knowledge theme, participants were able to explore existing relationships in the structure and propose enhancements. Participants were able to learn about the knowledge theme, though what they learned was related to providing a context and a general view of the knowledge theme and not a traditional introduction to a knowledge area. For ViDESK usage, context plays a significant role. The provision of a context for reasoning about content in a knowledge theme can be provided by using the ViDESK prototype that provides a high abstraction level to describe it.

EXPERIMENTAL CONCLUSION 3: SUPPORT DATA SOURCE ANALYSIS

Provide the means for data source analysis based on a given structure for knowledge sharing by comparing the structure with data source information that can be used both as feedback to enhance the structure, and to assist in data source information retrieval.

Related assumption is:
(2.4) **–** it is possible for users to compare the knowledge theme with data source information provided by the visualisation.

Based on this assumption and on experiment 2 results, the following conclusion can be made:

- assumption 2.4 was discussed under work objective 3.

The use of the information visualisation facility has proved to be the most difficult ViDESK facility to learn for the experiment 2 participants. Although, some participants were able to make some conclusions about how a particular data source has content related to the context of the knowledge theme view. However, most of the participants did not understand the support offered by the ViDESK prototype for comparing the context with a particular data source. The reasons seem to be the difficulty in dealing with abstraction and their theme expertise. As a result, few of the experiment 2 participants were able to take advantage of the information visualisation facility as feedback to enhance the structure.

EXPERIMENTAL CONCLUSION 4: PROVIDE A CONTEXT META-DESCRIPTION TO ANALYSE AND COMPARE DIFFERENT DATA SOURCES

Allowing user support to start, generate and analyse data source information retrieval results in a given knowledge theme context.

Related assumption is:
(2.4) – it is possible for users to compare the knowledge theme with data source information provided by the visualisation.

Based on this assumption and on experiment 2 results, the following conclusion can be made:

- assumption 2.4 was discussed under work objective 1.

Although not much evidence was collected regarding this work objective, participants considered it as one of ViDESK's most useful facilities and one reason to justify its use. Participants understand the two modes to generate queries and were able to use them. When asked to choose from available results, participants tended to choose documents based on their description in equal number to those who picked the first entry from the hit result list. This may indicate a growing participants awareness when compared to more traditional selections from listing results where up to 90% of people choose the first result in the list [Introna and Nissenbaum, 2000]. Regarding the use of ViDESK to compare different data sources, no data were collected though some participants report that they would like to test ViDESK with their own databases to check if their own data environment is representative of the knowledge theme view.

To close the work, chapter 9 – **Conclusions and future work**, presents the work conclusions, reporting further related work to be conducted and a number of recommendations resulting from efforts taken to develop and evaluate a *visualisation design for sharing knowledge*.

9 Conclusions and future work

The research problem of how to share knowledge between a group of people, in particular people engaged in learning activities together has been dealt with by the creation of a *Visualisation Design for Sharing Knowledge* – ViDESK.

Following ideas presented in chapter 4 – **Graphical support for knowledge sharing**, a structure for knowledge sharing specifying a knowledge theme and a two-part visualisation were proposed. They were designed to convey information for knowledge sharing and to be explored by a group of people engaged in collaborative learning. Chapter 5 – **A model for a visualisation for knowledge sharing**, proposed a planet-based metaphor for the visualisation design and specified the requirements from which a prototype was developed and presented in chapter 6 – **Implementing a knowledge sharing system**. Using that implementation the evaluation strategy presented in chapter 7 – **Experiments to evaluate the system in use**, proposes a task-based assessment of how a group of people can use ViDESK for collaborative learning. In particular, a series of three experiments were described to assess how the structure for knowledge sharing can be used to describe a knowledge theme, if and how each user takes advantage of the visualisation design to explore the knowledge theme conveyed, and how a group of people can use the system for collaborative learning.

Finally, a selection of the results gathered during the ViDESK prototype evaluation were presented and analysed in chapter 8 – **Experimental Results**. They show that it is possible for an expert to use the structure for knowledge sharing to specify a knowledge theme. Also, users were able to interact with the visualisation to explore information about the structure for knowledge sharing, and a group of users were able to use the system for collaborative learning.

This chapter reports the work conclusions and future work. The work objectives presented in chapter 1– **Introduction**, section 1.3 are discussed in section 9.1. The major contributions of the thesis are presented in section 9.2.

Additional remarks and further work proposals are given in section 9.3 – Future work. The thesis concludes with section 9.4, where it is restated that visualisation has great potential to convey information for knowledge sharing.

The chapter ends up with a number of recommendations for conducting studies similar to the one presented.

9.1 Objectives of the work re-visited

The Visualisation Design for Sharing Knowledge proposes the combined use of the structure for knowledge sharing and the 3D interactive visualisation to support collaborative learning. The work deals with the problem of how to share knowledge among a group of people engaged in learning activities together.

The work objectives were to:

- *support collaborative learning* by providing a visualisation to convey the structure information, and allow that structure to be shared among users. The evaluation has shown that people were able to answer the questions about the knowledge context specified by the structure for knowledge sharing being used, as reported in experiment 2 evaluation. The system itself allows user support for reasoning about the concepts, how they relate and to explore further their meaning, as observed in the three experiments reported. As people experimented with the system, and discussed a common structure for knowledge sharing they also collaboratively enhanced their knowledge, and thus learnt from each other about the knowledge context being shared as shown by experiment 3.
- *minimise cognitive overhead* through visualisation. As a result of having an externalisation of a knowledge context, users were able to reason about and discuss the context, based on the ability to use the visualisation and chat to track changes, detail relationships between concepts, as suggested by results from both experiment 1 and experiment 2.
- *minimise information overload*: the visualisation deals with the information overload problem by using a reduced set of symbols in the visualisation and adding control to its selective display. Users in experiment 2 took advantage of the ViDESK system by using the context conveyed by the structure and its visualisation to perform a number of search activities to a data source. As reported in experiment 2, most of the users were able to select relevant documents regarding the knowledge context being shared.

A number of additional experimental conclusions were obtained taking into consideration the detailed results reported in appendix C – **Experimental data**:

- *ease user interaction*: provide a common interface independent of different knowledge themes. Users were able to explore the structure for knowledge sharing as reported by experiment 2. They were also able to discuss and enhance a structure for knowledge sharing using the visualisation as a representation to support their discussion, as reported by experiment 3.
- *the provision of a high abstraction level to describe a given knowledge context*: allowing a high description level for use in collaborative learning to discuss models, and conceptual relationships and confront different perspectives on a given knowledge theme. Based on experiment 3, it is possible to say that using the system provides a different focus on discussion when compared to face to face situations. The system users tend to focus more on the concept relations than on the number of concept and keyword proposals, leading to a tighter network of concepts, as reported by experiment 3.
- *support for data source analysis*: based on a given structure for knowledge sharing by comparing the structure with data source information. As reported by experiment 2, most of the users were able to choose from a result list of related documents, using the ViDESK concept search facility. Observation suggests that users compared the description of the documents to the context represented by the visualisation in order to choose items other than the first of the result list entries.
- *a context meta-description with which to analyse and compare different data sources*: based on a given structure, this allows the user support to start, generate and analyse data source results within a particular context. Taking into consideration experiment 1, where a number of experts specified a structure for knowledge sharing and its representation, they were able to relate the context they created to the data source. From users remarks, as stated in the experiment 1 report, it seems they were able to comment how the data source may have some related content. In the situations where knowledge subjects are about subjects other than *Information Management*, the resulting information visualisation provides no useful information. Some of the users asked if they could use the system for their own related subject theme resources, as reported

by experiment 1. However, further work needs to be conducted to assess the extent of this advantage.

9.2 Summary of contributions

The proposed 3D interactive visualisation is the main contribution of this thesis, with its visualisation and support for knowledge sharing based on a structure that can be specified either by experts or enhanced collaboratively. It provides a high level approach to represent abstract information and offers a way to link it with real world data. Thus it supports the externalisation of a knowledge theme for a group of people to use together.

The visualisation can be used and explored by users in browsing and searching strategies and in reasoning about search results in ways that allow the making of comparisons based on the context provided by the structure for knowledge sharing.

The following items summarise the ViDESK contributions:

- it provides a way to convey high-level abstract information by using a structure to represent a knowledge context to be shared and enhanced collaboratively and a 3D interactive visualisation to convey structure information.
- it gives generic support to convey knowledge for collaborative learning. It also supports collaborative learning and learning.
- it takes it possible to integrate knowledge and data sources in the same interface. ViDESK supports data source content analysis for a particular context specified by a structure for knowledge sharing.
- it helps us to learn how to design experiments to assess visualisations of shared knowledge.

Evidence to support these claims came from the discussion of work objectives based on experimentation results, and is summarised as follows:

- *support collaborative learning* (work objective 1). Collaborative learning is defined as groups working together for a common learning purpose. The experimentation shows the potential of using ViDESK ideas to support collaborative learning in a higher education context. All ViDESK users report to learn and being able to both discuss and make contributions to the structure for knowledge sharing. Results show that participants perform best if they have some experience using computers and previous knowledge of the theme being discussed

- *minimise cognitive overhead* (work objective 2). Cognitive overhead concerns the problem of a user getting confused or experimenting difficulties in choosing the correct action. The use of the ViDESK ideas allows to minimise cognitive overhead by providing a direct manipulation 3D interactive visualisation where each participant can control, explore and manipulate a visual representation of the structure for knowledge sharing. Results show that participants were able to use multiple perspectives and discovered conceptual relationships, although a small number reported difficulties using the visualisation.
- *Minimise information overload* (work objective 3). Information overload concerns the problem of a user getting more information than he/she can cope with. ViDESK offers a tool for both the participant individual exploration and group sharing of the structure for knowledge sharing. Participants were able to explore the structure relationships and constructed alternative views of the structure, using the criteria space. Although participants were able to use ViDESK, results showed that just a small number of participants benefited from using the criteria space visualisation.

Also, a number of experimental conclusions were made. They demonstrate that ViDESK can increase interaction, providing a high-abstraction level and support for data source analysis. Experimental conclusions are summarised as follows:

- *ease user interaction* (experimental conclusion 1). User interaction concerns the user's relationship with other users and with information artefacts such as the one presented by the ViDESK prototype. The visualisation provides an interface for participant discussion and enhancement of the structure for knowledge sharing. Experimental results show that the visualisation supports participant's interaction within the group by proposing a knowledge shareable representation. Experimental results show the need of complementary support as the use of more traditional text based tools as the chat tool for interaction between participants to support discussion and negotiation.
- *the provision of a high abstraction level to describe a knowledge context* (experimental conclusion 2). This facility increases collaborative learning by

helping discussing models, concepts relationships and confronting perspectives about a given knowledge theme. Experiment results show that participants were able to reason about the knowledge theme being represented, and were able to explore existing relationships in the structure and to propose enhancements. Participants were able to learn about the knowledge theme although what they learned was related to providing a context and a general view of the knowledge theme.

- *support for data source analysis* (experimental conclusion 3). Experiment participants were able to perform data source analysis based on comparing the structure with data source information that can be used both as feedback to enhance the structure, and to assist in data source information retrieval. The use of the information visualisation facility has proved to be difficult for the majority of the participants. As a result, few of the experiment 2 participants were able to take advantage of the information visualisation facility as feedback to enhance the structure.
- *a context meta-description with which to analyse and compare different data sources* (experimental conclusion 4). Participants consider ViDESK as a useful facility and were able to understand the two modes to generate queries (concept and keyword). Regarding the ViDESK use for comparing different data sources no evidence of data were collected although some participants report that they like to test the use of ViDESK with their own databases to check if their own data environment is representative of the knowledge theme view.

9.3 Future work

This section briefly presents a number of issues resulting from the work described in this thesis. In particular, the discussion addresses further work that can be organised for evaluation, ViDESK prototype enhancements, and potential ViDESK applications.

As a result of the ViDESK evaluation, the following issues deserve further study and could be researched in the future:

- experiment 1 was oriented to assess how an expert can use a structure for knowledge sharing to specify a knowledge theme, including the use of the concept space visualisation to represent it. Further work should be conducted in order to assess how users can explore and use the structures constructed by the experts. Existing structures can be tested in a collaborative setting to assess if they are useful. Also the data already gathered can be further analysed. The spatial positioning of concepts specified in the visualisation also needs further research in order to assess its impact in the visualisation and how experts would prefer to organise it.

- experiment 2 deals with how a user can explore the knowledge theme taking advantage of the visualisation and the ViDESK system. Further work should be conducted in order to analyse all the other variables in the data gathered from the questionnaires and not considered in this study. In particular, the participants' responses for task 2 concerning structure content could be explored in order to discover why participants propose the concepts they propose. An interesting additional study would be a study of the impact of user contributions in the concept space visualisation by allowing users to explore the relations of their contributions with the existing structure. Further study should concern the impact of using the visualisation to answer more complex problems about the knowledge theme. Further work is also needed to study usefulness of the criteria space and, in particular, of the Information Visualisation facility within the criteria space.
- experiment 3 was oriented towards how the ViDESK system could be used to support collaborative learning by allowing a group to enhance a structure for knowledge sharing. Further work should be conducted in order to analyse all the collected data from observing participants interacting for completing task 3.1. It would also be useful to analyse navigation in the concept space visualisation. This analysis should take into account zoom, translation and rotation actions. Also, the study of navigation in the criteria space visualisation must be considered: which of the eight octants were viewed and in what sequence. Additionally, more participants should be involved in experiment 3 in order to confirm reported results. With a greater number of participants it would be possible to compare questionnaire and task results with the participants' level of computer and subject expertise.

Besides the need for further evaluation the work undertaken opens a wide range of problems that remain unanswered. The ViDESK prototype itself can be further developed to include, among others, the following:

- more advanced hardware interfaces such as the use of 3D input devices for navigation and 3D glasses or other output devices. This allows us to seek better ways for users to interface with the virtual environment. In experiment 2 a group of users reported some difficulties in using the keyboard and mouse to interact with the visualisation design.
- improved network support and visualisation refreshing for better response times, which, in turn, can augment system functionality. Better network support would allow to increase the number of users involved in experiment 3 groups.
- improved input data for the concept location, taking advantage of the available absolute and relative positioning facilities. This would extend the concept positioning facilities, giving users more power to organise the concept space visualisation, resulting in better awareness of the spatial positioning of concepts, an observed difficulty during experiment 1, where experts construct their concept spaces.
- Extensions to the criteria space visualisation to allow the use of multiple keywords and Boolean logic for composing each of the three possible criteria to render the criteria space. This extends the system support for reasoning and establishing of complex relationships using the structure for knowledge sharing. This is a direct response to some complaints reported by users on exploring the visualisation design in experiment 2 evaluation.
- incorporation of Dublin Core [Weibel and Lagoze, 1997] and other textual based classification systems to inform the Information Visualisation, allowing better content analysis for existing data sources. This allows the use of other textual search engines and provides a middle layer to describe how a knowledge context can be translated into specialised classification tokens to be used for information retrieval. This results from several remarks made by experts in experiment 1.
- include gesture support in the voting tool by sensing users' rising hand actions [Gouveia and Gouveia, 2000]. This may lead to a more integrated user interface, involving users and focusing them in the structures enhancement and not in the voting process (enhancing the feel of presence). The observed action on voting, in experiment 3 evaluation, shows that using the voting window is sometimes difficult regarding the screen size and the need to explore the visualisation design.

Additionally, a number of other applications for the ViDESK model, other than collaborative learning support, can be considered:

- *Information Retrieval* support: as a result of the Information Visualisation, the ViDESK prototype can be used to analyse and compare the knowledge theme with information from a given data source or a set of data sources. The Information Visualisation in this case can be used as a tool for analysing semantic similarity between the tacit knowledge being shared and the data source content. This application needs to be tested and evaluated to assess its feasibility.
- *Integrated Learning Environments* are composed of a set of tools that assist learning activities and content access for a number of users [Gouveia et al., 2000a]. This includes tools for collaboration, pedagogical issues, multimedia support, and information management. ViDESK can be used to complement content requirements within a particular context given by the structure for knowledge sharing.
- *Workflow*: learning about a particular working environment. ViDESK could be used to help new workers learn about the general working context and available detail about the way information is used. In this particular application, activities can be defined as concepts and keywords as resources. Thus, the visualisation supports the sharing of meaning about the work context.
- *Knowledge Management*. Using additional annotation facilities and a recommender system, ViDESK could be extended to assist knowledge management by providing both an interface for existing knowledge databases and a knowledge annotation tool.
- *Content Management*. As a visual interface for content management ViDESK would support different views independent of the content itself. The ViDESK prototype can be integrated in a system like EFTWeb as an operation service [Gouveia et al., 2000b].

9.4 Conclusions

The structure for knowledge sharing supports the representation of knowledge themes, which provide contexts that can be used in a higher education setting. The structure can be used to share context knowledge and the 3D interactive visualisation as an interface for enhancing this context by a group of people.

The system can be used to collaboratively enhance the structure to express the group's view. The visualisation design can be used to convey structure information providing a feasible interface for individual user exploration and group sharing.

The ViDESK system specific addresses the needs of sharing knowledge by allowing a group of students to share meanings and elaborate a common ground for understanding and "think together" about a knowledge theme or context. The ViDESK system proposes a virtual environment approach to introduce the co-construction of knowledge and provide the experience of discussing and enhancing a context following a constructionist approach. In particular, a number of pedagogical needs are satisfied, related to the construction of a network of concepts, negotiate meanings and explore concepts relationships that allow users both individually and within a group to organise and share knowledge by providing a common representation to their efforts.

Although further research work needs to be undertaken, preliminary results seem to confirm most of the work objectives as presented in section 9.1.

The use of the ViDESK, in particular its 3D interactive visualisation offers an alternative approach to organising information about a given topic by taking advantage of using a 3D space. The learning effects resulting from this approach are the most vivid experience in interacting with the network of concepts used to share knowledge and the possibility to present available information in a similar spatial environment to the one where people work and live. However, considering the ViDESK actual prototype, several issues arise concerning its usability. The proposed virtual environment can be enhanced by using alternative hardware as head mounted displays and virtual reality input devices and thus reinforce the notion of its learning benefits. The use of such hardware improvements provides a more precise assessment of ViDESK potential, specially the advantages of using a 3D interactive visualisation. Resulting from evaluation, a number of issues concerning the interface and constraints in exploring the visualisation and the collaboration support shows some limitations that may impact on assess how much the system can support learning and also the learning extent on users. This may also provide additional findings on ViDESK learning effects.

Considering the learning issues a number of findings were made that make visible various kinds of learning resulting from using the ViDESK system. Beyond the understanding of the ViDESK visualisation as a context representation that has been successfully tested and where users showed to be able to explain the representation to others, a number of learning effects were also visible.

The ViDESK has been designed to support collaborative learning by sharing knowledge as a network of concepts. The resulting context is co-constructed collaboratively by involving individuals and producing a number of learning episodes from which the following are examples:

- the ViDESK concept space visualisation provides a context representation as a network of concepts. By exploring it, a number of users were able to support their reasoning and propose new concepts to expand the context. They were also able to consider and discuss concept relationships, developing a new understanding of concept meanings and its impact within the represented context. A number of learning effects were observed as the case of users engaged in experimenting ViDESK, gain the capacity to propose new valid structure elements and discuss among them its impact. In this case, they learn by doing, constructing and arguing (qualitative detail has been provided in appendix C).

- resulting from using the ViDESK system both in stand alone or collaborative mode, a number of learning episodes were identified. Asking users to describe the learning outcomes from using the system, some of them reported learning effects that can be classified as situations where reflective learning takes place. In particular one user reported that it was just when proposing a new concept and arguing about its need that he realised that another concept fulfils the need, showing him a perspective that he was not able to follow without being involved in discussing it. Another example was provided by a user that reports to gain an approach to organise and structure information about what to know within the context. The user also reports that the system provides the opportunity to analyse for missing relationships and inconsistencies. The user adds: "*I now realised that what I really know about this context needs to be thought through and further developed*".

The use of 3D interactive visualisation proved to be feasible to support the sharing of knowledge. The use of a virtual world allows representation of high-level abstract information. Although the evaluation undertaken was not able to fully demonstrate this, users should interact with the visualisation design to assist them in comparing data source information with the knowledge theme being shared. This could provide a tool for comparing different data sources based on a given knowledge context which allow an overall semantic data source analysis to take place.

The ViDESK system provides the opportunity to dynamically support the co-construction of knowledge using a digital support and offering a 3D interactive visualisation that conforms to the notion of mental models as visual enabling network of concepts for describing a knowledge theme or context as introduced by Damasio [Damasio, 1994].

The system contribution that a 3D visualisation provides in contrast to a 2D visualisation is the offering of additional semantics to be explored for organising information and thus provide a more natural approach to individuals the negotiation of a common base of meanings concerning a particular knowledge theme. In particular, there is no need to make a projection of the three real world dimensions to the two available in the 2D case. It also provides the possibility to share a visualisation that can be explored and viewed in alternative views not by explicit use of some form of semantic operation but just by inspecting the 3D visualisation as we do in real world activities with real world objects. The main issue is to provide a virtual environment where the ViDESK visualisation can be used as knowledge objects representation to share knowledge and support collaborative learning.

Considering the use of traditional tools for supporting learning among a group of individuals such as whiteboards, sticky notes or index cards, the use of computer-based external representation provides a potential for digital integration. When compared to other lower-tech representations, the ViDESK visualisation offers the possibility to integrate a high-level semantic model for knowledge sharing within the computer where databases and other educational content may exist and be potentially related, retrieved and explored. Additionally, the use of a virtual environment will allow both representation of users (by embodiment) and knowledge, information and data as also the linkage with real world by the use of sensors. This provides a richer environment particularly considering the time/space constraints and the potential use on distance education and e-learning environments.

A final remark relates to the issue of using 3D facilities as a new means of providing highly abstract information as an alternative to organising information and knowledge. The creation of such “representation languages” can be seen as a promising research field to which ViDESK can hopefully be considered a small contribution.

9.5 Recommendations

Based on the present work, a number of recommendations are presented. These recommendations concern the visualisation research area, the prototype development and related educational issues.

Concerning visualisation research, two recommendations are presented, based on the ViDESK visualisation:

- Visualisation has a huge potential as a high-level integration interface. Visualisation seems to have a high number of benefits regarding information and knowledge representation. Most of the visualisation potential remains undiscovered.
- the creation of virtual environments for representing information and knowledge requires a multidisciplinary approach. In particular the research can benefit from taking into consideration educational issues.

Based on the development of the ViDESK prototype, three additional recommendations are presented as a result of its developing effort:

- use of Java and Java based technologies for prototype development. Allows to use an inexpensive platform development, widely documented and easy to run and test on the most used platforms (hardware and software). It offers a wide range of technologies to assist development and offers many opportunities to reuse third part code for many applications.
- minimise the use of state-of-the-art hardware. Although virtual environments need improved input and output devices, this could impose a number of restrictions and pose many development challenges. Among these are imposed restrictions to development platforms and lack of information/support available.

A lot of visualisation and virtual environment research and evaluation can be conducted using traditional hardware.

- when possible use the World Wide Web as the test bed. For testing the World Wide Web provides a unique data set with multimedia and unstructured information as well as a rich set of formats and contexts to use. Its availability and inexpensive characteristics turn the Web into a low cost alternative for a testing environment.

Concerning educational issues related to visualisation and virtual environments, two more recommendations are presented. They are based on the evaluation work done with the ViDESK prototype:

- for evaluation adopt a task-based strategy. As visualisation and virtual environments evolve, a number of issues remain unsolved. The use of tasks for evaluation focuses the activity and facilitates both on evaluation and data gathering.
- focus on user emotion activators instead of processes. Each student has his/her own motivations and learning triggers. To be engaged he/she must be "touched" and have some emotion reinforcement for working with information and knowledge. There is no unique and secure process for making someone learn and one of the best ways to do it is to promote interaction between students.

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Appendix A

Structure for knowledge sharing: issues and examples

This appendix presents the internal representation of the structure for knowledge sharing and briefly discusses scalability issues regarding the use of the structure and its visualisation.

In addition, are also three example structures for knowledge sharing about the *Information Management* knowledge theme described. Each structure is presented with its concept list and, for each concept, the keywords and corresponding keyword ratings.

A.1 The internal representation of the structure for knowledge sharing

To allow the computer use of the structure for knowledge sharing, some information must be stored for the structure elements (concept, keyword and keyword rating). Taking advantage of the structure composition, two groups of information objects were defined. These are concept object which represent the structure concept element, and the keyword object which represents the keyword and keyword rating structure elements.

The concept and keyword objects are used as the internal representation for the structure elements. The description of each of the two objects is given in the form of tables that describe the name of the field, a short description for it, and its suggested computer representation data type.

The concept object has eight fields (Table 15). A *name* field is used as the identifier for each particular concept. The field *type* allows three different types of concepts within the concept space, giving the opportunity add extra semantics to each concept. The two next fields, *ICNumber* and *DateCreation* support reference information for the concept and its creation date.

The concept object contains most of the data needed for rendering the 3D interactive visualisation, including the position of the concept in the concept space given by the x, y, z co-ordinates – *ICPosX*, *ICPosY*, and *ICPosZ* fields. The last field gives a short description of the concept.

CONCEPT		
Name	The name for the concept, can be up to three words	String
Type	Concept types; defined as Critical, Base and Normal	Char
ICNumber	The code of the concept, to be used to refer it	Integer
DateCreation	Timestamp for concept creation, in a full date format	Date
ICPosX	Value for the X space position	Float
ICPosY	Value for the Y space position	Float
ICPosZ	Value for the Z space position	Float
Description	A short description of the meaning and goal of the concept	String

Table 15: *Concept* object representation

Table 16 shows the structure for the keyword object. The keyword object includes two elements of the structure for knowledge sharing: the keyword and the keyword rating.

There are six keyword object fields. The *name* field with the identifier word for the keyword. A field named *type* is for future use. It also indicates if the keyword object was created from an initial setup or results from user enhancements. The field *rating* represents the keyword rating for the concept referenced by the field *ICNumber*. The field *DateCreation* stores the date and time of the keyword creation and *UseElement* gives the version number of the keyword object – it counts the number of modifications to the keyword object fields.

KEYWORD		
Name	The name for the keyword, must be just one word	String
Type	For future use, allocated I, initial set-up, and S, standard use	Char
Rating	The rating element, a value in the range 0.00 to 1.00 (inclusive)	Float
ICNumber	The concept reference with which the keyword and keyword rating are associated	Integer
DateCreation	Timestamp for keyword creation, in a full date format	Date
UseElement	Version number, counts updates in the keyword object fields	Integer

Table 16: *Keyword* object representation

A.2 Example of structures for knowledge sharing

A.2.1 The selected knowledge theme

In order to test how the structure for knowledge sharing can be used for specifying a knowledge theme view we selected the theme *Information Management*. This knowledge theme was considered because:

- the author teaches an undergraduate and a graduate course on Information Management;
- there are available students to test the structure for knowledge sharing;
- there are available experts to test the structure for knowledge sharing;
- the knowledge theme characteristics are useful and meaningful even for other students from different areas of interest.

The structure for knowledge sharing about *Information Management* has been built based on two papers and following the material provided by Wilson textbook [Wilson, 1997].

The two papers are:

- Butcher, D and Rowley, J. *The 7 R's of Information Management*, Managing Information, March 1998 (vol 5, n. 2);
- Choo, C. *Information Management for the Intelligent Organization: Roles and implications for the information professions*. Digital Libraries Conference, March 27-28, 1995, Singapore.

A small version of the built structure for knowledge sharing *about Information Management* was presented to an undergraduate class on *Information Management* for discussion. From testing the structure, minor corrections have been made, mostly by adding more keywords or correcting some wording to improve understanding of the structure.

A.2.2 Three structure examples

The structure for knowledge sharing about the *Information Management* theme has three versions. The decision to build three versions is related with the time needed to learn from each one and their complexity. The three versions have an increased number of concepts and keywords, so they progressively represent a richer and more complex *Information Management* knowledge theme.

The three structures are presented in this appendix. The small scale version is in A.4, the medium scale version is in A.5 and the large scale version is in A.6. The main differences between these versions are the number of structure elements.

For each of the structure versions, a number of characteristics are recorded as these characteristics may impact the complexity of the structure and the visualisation design:

- *total number* of concepts and keywords;
- *minimum*, *maximum*, and *average* number of keywords by concepts. These values provide information as to how the structure concepts are defined;
- *unique keywords used*, which allows the analysis of how many different contributions were made to the structure. By indicating the number of these keywords we also have the number of repeated keywords, which contribute to the conceptual relationships;
- *unique keywords* and the total number of keywords allowing us to compute the degree of common keywords for the structure. This value gives an indication of how many potential relationships can exist between concepts;
- *most used keywords* and their number of occurrences which helps to indicate the keywords that relate to more concepts in the structure.

A.2.2.1 SMALL SCALE VERSION: 17 CONCEPTS

This is the smaller scale structure for knowledge sharing. It has 17 concepts and provides a knowledge theme view oriented to the use of computers and Information Management practice providing a general introduction to the theme. The small structure version was selected for the work evaluation. The small structure version characteristics are summarised in Table 17. The complete structure is presented in appendix A.4.

Total number of concepts	17
Total number of keywords	160
Maximum number of keywords by concept	18
Minimum number of keywords by concept	0
Average number of keywords by concept	9,4
Total number of distinct keywords	67
Most used keywords	**Number of occurrences**
decision	9
cost	9
information	8
value	8
structure	6
technology	6

Table 17: Example structure characteristics, small version

A.2.2.2 MEDIUM SCALE VERSION: 30 CONCEPTS

The medium scale version of the structure for knowledge sharing on the *Information Management* theme has 30 concepts and provides a more operations-oriented view of the *Information Management* knowledge theme. The structure provides a context more closed related with the issues of Information Management in the organisation.

The medium scale version structure for knowledge sharing characteristics about *Information Management* is summarised in Table 18. The complete structure is presented in appendix A.5.

Total number of concepts	30
Total number of keywords	332
Maximum number of keywords by concept	24
Minimum number of keywords by concept	2
Average number of keywords by concept	11,1
Total number of distinct keywords	93
Most used keywords	**Number of occurrences**
value	12
operation	10
decision-making	9
management	8
information	8
human	8

Table 18: Example structure characteristics, medium version

A.2.2.3 LARGE SCALE VERSION: 45 CONCEPTS

This is the largest scale structure of the three considered. It comprises 45 concepts and augments the Management-related concepts in the structure. However, most of the concepts added do not have associated keywords. This means that most of the characteristics of the large scale version of the structure remain the same when compared with the medium version, as summarised in Table 19. The complete structure is presented in appendix A.6.

Total number of concepts	45
Total number of keywords	332
Maximum number of keywords by concept	24
Minimum number of keywords by concept	0
Average number of keywords by concept	7,4
Total number of distinct keywords	93
Most used keywords	**Number of occurrences**
value	12
Operation	10
decision-making	9
Management	8
Information	8
Human	8

Table 19: Example structure characteristics, large version

A.3 Visualisation scalability issues

One important issue is how the two-part visualisation deals with scaling problems. There scale is understood to be the number of structure elements (concepts, keywords, and keyword ratings) to be represented.

For the examples presented, data is summarised on Table 20. These values provide information on the impact that the number of structure elements has on the model algorithms and the visual elements to be rendered.

Notice that each of the two visualisations is impacted in different ways by the scale of the structures for knowledge sharing. The concept space visualisation must render the spheres and lines, being more sensitive when the number of keywords grows. This way, the medium and large scale versions of the example structure, while having a different number of concepts, have an equal number of keywords, so there is not much difference in the impact that taken to render both visualisations.

The criteria space visualisation is much more sensitive to the number of concepts because it has a limited 3D space in which to place them. Therefore, for the criteria space visualisation there is a great difference between the medium and large scale versions of the example structure.

Table 20 shows how the structure elements can have a visual representation based on a lower level of complexity when comparing the number of visual elements with the structure elements.

	Small version	Medium version	Large version
Structure elements and related stuff			
Concepts	17	30	45
Keywords	160	332	332
Keyword ratings	160	332	332
Semantic distance (concepts) pairs	136	435	1015
Keywords overlapping rate (ratio between repeated and all keywords)	58%	72%	72%
Expected non zero semantic distance (based on keyword overlapping rate)	79	313	731
Nonzero semantic distance (based on the semantic distance algorithm)	75	238	238
Visual elements			
Number of spheres	17	30	45
Number of lines (red and blue lines)	33	89	89
Red lines (strong relationship)	0	4	4
Blue lines (upper medium relationship)	33	85	85

Table 20: structure and visualisation elements for the structure examples

The number of structure elements has also an upper limit determined by the complexity of the described context, and hence yet be useful and understandable. Clearly, when an expert describes a knowledge theme, he/she adopts a perspective that limits complexity and thus the number of structure elements. A similar situation occurs with a group of people. This may require further research into using a system such as ViDESK in order to determine the limits on concept and keyword numbers concerning the description of usable knowledge area.

A.4 Small scale version of the Information Management structure for knowledge sharing

The structure is composed by the following 17 concepts:

1 Business - Critical - the process of making added value activities.

2 Communication - Base - data or information flow between any two humans or organisations.

3 Computer - Base - the information artefact "par excellence".

4 Data - Base - The raw material to represent reality.

5 Database - Base - the technology to store and retrieve data.

6 Enterprise - Base - a group of people and resources organised to meet a set goal.

7 Human - Base - the people, human resources.

8 Information - Critical - the relevant data that support decision-making.

9 Knowledge - Critical - the structure and long term information that can be reused.

10 Management - Critical - set of skills to support business decisions, planning and control.

11 System - Normal - a ground concept of unity and utility.

12 Task - Normal - A precise action to be executed.

13 Technology - Critical - tools that help human.

14 Telecommunication - Normal - Distant communications, normally by computer.

15 User - Normal - humans that operate (use) the technology.

16 Value - Critical - Perceived benefit for a given item.

17 Work - Base - Activity developed by human for which they are paid or recognised.

Information Management
17 concepts

1 Business - Critical -
- application - 0.25
- company - 0.65
- competitive - 0.45
- cost - 0.45
- culture - 0.25
- customer - 0.7
- decision - 0.5
- financial - 0.65
- information - 0.62
- legacy - 0.25
- management - 0.65
- model - 0.45
- operation - 0.5
- organisation - 0.35
- planning - 0.55
- strategy - 0.45
- structure - 0.25
- value - 0.25

2 Communication - Base
- advantage - 0.15
- collaborative - 0.25
- communication - 0.55
- computer - 0.15
- concept - 0.25
- cost - 0.25
- culture - 0.2
- distributed - 0.45
- flow - 0.45
- human - 0.55
- influence - 0.55
- information - 0.65
- model - 0.25
- network - 0.55
- online - 0.25
- subsystem - 0.25
- technique - 0.25
- technology - 0.25

3 Computer - Base -
- access - 0.67
- automatic - 0.67
- cost - 0.25
- information - 0.45
- order - 0.67
- processing - 0.8
- technology - 0.7

4 Data - Base -
- data - 0.78
- operation - 0.5
- structure - 0.7
- value - 0.38

5 Database - Base -
- access - 0.65
- data - 0.6
- decision - 0.35
- information - 0.75
- legacy - 0.55
- retrieval - 0.5
- storage - 0.55
- structure - 0.78
- technology - 0.61
- transaction - 0.63

6 Enterprise - Base -
- company - 0.77
- cost - 0.25
- management - 0.76
- structure - 0.24
- system - 0.23
- technology - 0.44
- value - 0.56

7 Human - Base -
- customer - 0.43
- decision - 0.44
- education - 0.55
- human - 0.7
- individual - 0.7
- training - 0.67
- value - 0.55

8 Information - Critical -
- cost - 0.56
- decision - 0.67
- information - 0.9
- retrieval - 0.4
- structure - 0.67
- time - 0.56
- value - 0.66

9 Knowledge - Critical -
- assessment - 0.6
- confidence - 0.51
- cost - 0.16
- culture - 0.36
- decision - 0.79
- excellence - 0.66
- experience - 0.72
- human - 0.46
- information - 0.56
- organisation - 0.76
- perspective - 0.62
- strategy - 0.61
- theory - 0.56

10 Management - Critical
- analysis - 0.34
- assessment - 0.4
- control - 0.75
- coordination - 0.77
- decision - 0.65
- economy - 0.45
- influence - 0.3
- information - 0.59
- management - 0.91
- organisation - 0.66
- perspective - 0.55
- planning - 0.75
- value - 0.34

11 System - Normal -
- component - 0.49
- lifecycle - 0.45
- structure - 0.24
- subsystem - 0.59

12 Task - Normal -
- no keyword elements

13 Technology- Critical -
- change - 0.34
- cost - 0.34
- lifecycle - 0.55
- operation - 0.68
- technology - 0.74
- value - 0.78

14 Telecommunication - Normal -
- access - 0.45
- application - 0.55
- communication - 0.75
- computer - 0.7
- cost - 0.45
- data - 0.65
- distributed - 0.55
- network - 0.56
- online - 0.71
- technology - 0.45
- transaction - 0.45

15 User - Normal -
- decision - 0.34
- human - 0.78
- management - 0.34
- operation - 0.65

16 Value - Critical -

advantage - 0.32
assessment - 0.44
commitment - 0.34
confidence - 0.34
cooperation - 0.34
decision - 0.44
education - 0.47
experience - 0.34
expert - 0.34
influence - 0.44
information - 0.32
opportunity - 0.56
performance - 0.34
training - 0.44
value - 0.74

17 Work - Base -

company - 0.45
competence - 0.45
cost - 0.27
decision - 0.42
education - 0.55
employee - 0.75
experience - 0.45
goal - 0.6
human - 0.65
individual - 0.65
information - 0.55
management - 0.45
network - 0.55
operation - 0.45
service - 0.75
training - 0.51

A.5 Medium scale version of the Information Management structure for knowledge sharing

The structure is composed by the following 30 concepts:

1 Added Value - Normal - the additional advantage resulting from a given system or action

2 Audit - Normal - activity that leads to a better knowledge of processes/organisations

3 Benefit - Normal - what results from the overall value of a given concept, product or service

4 Business - Critical - the process of carrying out added value activities

5 Communication - Base - data or information flow between any two humans or organisations

6 Computer - Base - the information artefact "par excellence"

7 Data - Base - the raw material to represent reality

8 Database - Base - the technology to store and retrieve data

9 Decision - Critical - the process of choosing between information alternatives

10 Demand - Normal - request from the market for a given product or service

11 Digital - Normal - computer discrete based state of information

12 Education - Base - action where individuals acquire new information and training

13 Enterprise - Base - a group of people and resources organised to meet a set goal

14 Evaluation - Normal - an activity that deals with trying to assign a context value to something

15 Human - Base - the people, human resources

16 Implementation - Normal - the actions that lead to the actual operation of a system

17 Information - Critical - the relevant data that support decision-making

18 Information System - Critical - the subsystem of a system that deals with the information flow

19 Interface - Normal – the mediation between computers and users

20 Knowledge - Critical - the structure and long term information that can be reused

21 Logistic - Normal - set of activities that perform physical distribution

22 Management - Critical - set of skills to support business decisions, planning and control

23 System - Normal - a ground concept of unity and utility

24 Task - Normal - a precise action to be executed

25 Technology - Critical - the tools that help humans

26 Telecommunication - Normal - distant communications, normally by computer

27 Tool - Normal - a specialised aid to take some specific action

28 User - Normal - humans that operate (use) the technology

29 Value - Critical - perceived benefit for a given item

30 Work - Base - activity developed by humans for which they are paid or recognised

Information Management
30 concepts

1 Added Value - Normal
advantage - 0.55
cost - 0.24
currency - 0.3
economy - 0.44
goal - 0.5
intangible - 0.54
management - 0.64
money - 0.44
quality - 0.54
strategy - 0.4
value - 0.65

2 Audit - Normal -
account - 0.45
analysis - 0.65
assessment - 0.35
competence - 0.25
control - 0.25
customer - 0.45
data - 0.25
database - 0.15
decision-making - 0.25
diagnostic - 0.65
failure - 0.45
framework - 0.55
method - 0.25
organisation - 0.45
performance - 0.25
problem - 0.55
quality - 0.45
requirement - 0.5
subsystem - 0.55
system - 0.65
technique - 0.56

3 Benefit - Normal -
advantage - 0.56
goal - 0.36
intangible - 0.26
money - 0.46
tangible - 0.26
value - 0.56

4 Business - Critical -
analysis - 0.25
application - 0.25
company - 0.65
competitive - 0.45
culture - 0.25
customer - 0.7
decision-making - 0.5
economy - 0.45
employee - 0.45
financial - 0.65
influence - 0.6
legacy - 0.25
management - 0.45
model - 0.45
operation - 0.5
organisation - 0.35
planning - 0.55
politic - 0.65
prospective - 0.35
strategy - 0.45
structure - 0.25
system - 0.25
trend - 0.15
value - 0.25

5 Communication - Base
advantage - 0.15
collaborative - 0.25
communication - 0.55
computer - 0.15
concept - 0.25
cost - 0.25
culture - 0.2
distributed - 0.45
flow - 0.45
human - 0.55
influence - 0.55
information - 0.65
model - 0.25
network - 0.55
online - 0.25
subsystem - 0.25
technique - 0.25
technology - 0.25
theory - 0.25

6 Computer - Base -
automatic - 0.67
cost - 0.25
order - 0.67
processing - 0.8
technology - 0.7

7 Data - Base -
data - 0.78
operation - 0.5
structure - 0.7
value - 0.38

8 Database - Base -
access - 0.65
data - 0.6
decision-making - 0.35
order - 0.7
retrieval - 0.5
storage - 0.55
structure - 0.78
transaction - 0.63

9 Decision - Critical -
analysis - 0.6
change - 0.48
competence - 0.38
confidence - 0.45
cost - 0.78
decision - 0.78
decision-making - 0.78
evaluation - 0.58
experience - 0.38
expert - 0.18
information - 0.88
opportunity - 0.28
time - 0.48

10 Demand - Normal -
collaborative - 0.23
customer - 0.63
economy - 0.43
flow - 0.23
global - 0.43
management - 0.43
product - 0.63
time - 0.43
trend - 0.73

11 Digital - Normal -
automate - 0.5
automatic - 0.5
computer - 0.7
data - 0.62
database - 0.55
intangible - 0.23
legacy - 0.5
online - 0.6
processing - 0.3
retrieval - 0.4
storage - 0.52

12 Education - Base -
application - 0.25
assessment - 0.45
change - 0.55
collaborative - 0.55
collective - 0.45
communication - 0.35
competence - 0.35
culture - 0.65
expert - 0.65
human - 0.75
individual - 0.75

information - 0.62
training - 0.65
value - 0.45

13 Enterprise - Base -
company - 0.77
management - 0.76
structure - 0.24
system - 0.23
technology - 0.44
value - 0.56

14 Evaluation - Normal -
analysis - 0.37
assessment - 0.34
collaborative - 0.34
collective - 0.34
competence - 0.34
component - 0.34
data - 0.34
decision - 0.44
design - 0.34
diagnostic - 0.45
failure - 0.44
individual - 0.34
influence - 0.37
performance - 0.41
problem - 0.41
prospective - 0.47
trend - 0.41
value - 0.41

15 Human - Base -
competence - 0.3
customer - 0.43
decision-making - 0.44
education - 0.55
human - 0.7
individual - 0.7
politic - 0.45
training - 0.67
value - 0.55

16 Implementation - Normal
application - 0.55
change - 0.6
delay - 0.34
design - 0.65
development - 0.5
diagnostic - 0.45
failure - 0.45
lifecycle - 0.55
management - 0.65
method - 0.5
operation - 0.55
planning - 0.54
requirement - 0.51
subsystem - 0.53
system - 0.53

17 Information - Critical -
cost - 0.56
decision - 0.67
retrieval - 0.4
structure - 0.67
time - 0.56
value - 0.66

18 Information System - Critical -
access - 0.8
application - 0.5
automatic - 0.6
communication - 0.5
cooperation - 0.7
coordination - 0.6
data - 0.71
database - 0.81
decision-making - 0.5
distributed - 0.65
information - 0.7
online - 0.5
processing - 0.45
retrieval - 0.52
transaction - 0.6

19 Interface - Normal -
computer - 0.56
human - 0.8
operation - 0.76
order - 0.34

20 Knowledge - Critical -
analysis - 0.56
assessment - 0.6
confidence - 0.51
culture - 0.36
decision - 0.79
decision-making - 0.76
diagnostic - 0.56
excellence - 0.66
experience - 0.72
human - 0.46
information - 0.56
order - 0.56
organisation - 0.76
perspective - 0.62
strategy - 0.61
theory - 0.56

21 Logistic - Normal -
management - 0.51
material - 0.65
operation - 0.67
planning - 0.5
time - 0.53
transaction - 0.49

22 Management - Critical
analysis - 0.34
assessment - 0.4
control - 0.75
coordination - 0.77
decision-making - 0.65
economy - 0.45
influence - 0.3
management - 0.91
organisation - 0.66
perspective - 0.55
planning - 0.75
prospective - 0.55
time - 0.55
value - 0.34

23 System - Normal -
component - 0.49
lifecycle - 0.45
order - 0.27
structure - 0.24
subsystem - 0.59

24 Task - Normal -
account - 0.39
communication - 0.49
component - 0.39
cooperation - 0.5
coordination - 0.51
cost - 0.3
flow - 0.39
goal - 0.69
human - 0.59
individual - 0.49
operation - 0.59
order - 0.39
performance - 0.39
requirement - 0.39
training - 0.59
transaction - 0.61

25 Technology - Critical -
change - 0.34
lifecycle - 0.55
operation - 0.68
value - 0.78

26 Telecommunication -
Normal -

- access - 0.45
- application - 0.55
- communication - 0.75
- computer - 0.7
- cost - 0.45
- data - 0.65
- distributed - 0.55
- information - 0.56
- network - 0.56
- online - 0.71
- technology - 0.45
- transaction - 0.45

27 Tool - Normal -

- application - 0.77
- computer - 0.56
- goal - 0.61
- method - 0.7
- operation - 0.6
- performance - 0.43
- technology - 0.75

28 User - Normal -

- human - 0.78
- operation - 0.65

29 Value - Critical -

- advantage - 0.32
- commitment - 0.34
- competence - 0.36
- confidence - 0.34
- cooperation - 0.34
- decision-making - 0.44
- education - 0.47
- evaluation - 0.44
- excellence - 0.39
- experience - 0.34
- expert - 0.34
- influence - 0.44
- information - 0.32
- opportunity - 0.56
- performance - 0.34
- training - 0.44
- value - 0.74

30 Work - Base -

- company - 0.45
- competence - 0.45
- decision - 0.42
- education - 0.55
- employee - 0.75
- experience - 0.45
- goal - 0.6
- human - 0.65
- individual - 0.65
- information - 0.55
- management - 0.45
- network - 0.55
- operation - 0.45
- service - 0.75
- training - 0.51

A.6 Large scale version of the Information Management structure for knowledge sharing

The structure is composed by the following 45 concepts:

1 Added Value - Normal - the additional advantage resulting from a given system or action
2 Audit - Normal - activity that leads to a better knowledge of processes/organisations
3 Benefit - Normal - what results as from the overall value of a given concept, product or service
4 Business - Critical - the process of carrying out added value activities
5 Communication - Base - data or information flow between any two humans or organisations
6 Computer - Base - the information artefact "par excellence"
7 Data - Base - the raw material to represent reality
8 Database - Base - the technology to store and retrieve data
9 Decision - Critical - the process of choosing between information alternatives
10 Demand - Normal - request from true market for a given product or service
11 Digital - Normal - computer discrete based state of information
12 Education - Base - action where individuals acquire new information and training
13 Enterprise - Base - a group of people and resources organised to meet a set goal
14 Evaluation - Normal - an activity that deals with trying to give a context value to something
15 Human - Base - the people, human ressources
16 Implementation - Normal - the actions that lead to the actual operation of a system
17 Information - Critical - the relevant data that support decision-making
18 Information System - Critical - the subsystem of a system that deal with the information flow
19 Interface - Normal - the mediation between computers and users
20 Knowledge - Critical - the structure and long term information that can be reused
21 Logistic - Normal - set of activities that perform physical distribution
22 Management - Critical - set of skills to support business decisions, planning and control
23 Market - Normal - the overall set of potential customers
24 Marketing - Normal - the techniques used to attract the higher number of customers possible
25 Methodology - Normal - a given ordered set of methods to be applied in a precise context
26 Need - Base - a requirement for humans to take a decision or action (such as an information need)
27 Network - Normal - a interrelated set of independent points that can be humans, enterprises or computers
28 Process - Base - a given sequence of requirements where activities have to be performed
29 Product - Normal - a given material good
30 Production - Normal - making products
31 Purchasing - Normal - acquiring products or services
32 Requirement - Base - a specification under context for operation
33 Risk - Base - sense/probability of losing in taking action
34 Service - Base - set of activities that involve the provision of intangible as tangible goods
35 Society - Normal - group of people with their cultural habits
36 Specification - Base – a sentence expressing a need
37 Success - Normal - degree of satisfying a specific goal
38 System - Normal - a ground concept of unity and utility
39 Task - Normal - a precise action to be executed
40 Technology - Critical - the tools that help human
41 Telecommunication - Normal - distant communications, normally by computer
42 Tool - Normal - a specialised aid to take some specific action
43 User - Normal - humans that operate (use) the technology
44 Value - Critical - perceived benefit for a given item
45 Work - Base - activity developed by humans for which they are paid or recognised

Information Management
45 concepts

1 Added Value - Normal
- advantage - 0.55
- cost - 0.24
- currency - 0.3
- economy - 0.44
- goal - 0.5
- intangible - 0.54
- management - 0.64
- money - 0.44
- quality - 0.54
- strategy - 0.4
- value - 0.65

2 Audit - Normal -
- account - 0.45
- analysis - 0.65
- assessment - 0.35
- competence - 0.25
- control - 0.25
- customer - 0.45
- data - 0.25
- database - 0.15
- decision-making - 0.25
- diagnostic - 0.65
- failure - 0.45
- framework - 0.55
- method - 0.25
- organisation - 0.45
- performance - 0.25
- problem - 0.55
- quality - 0.45
- requirement - 0.5
- subsystem - 0.55
- system - 0.65
- technique - 0.56

3 Benefit - Normal -
- advantage - 0.56
- goal - 0.36
- intangible - 0.26
- money - 0.46
- tangible - 0.26
- value - 0.56

4 Business - Critical -
- analysis - 0.25
- application - 0.25
- company - 0.65
- competitive - 0.45
- culture - 0.25
- customer - 0.7
- decision-making - 0.5
- economy - 0.45
- employee - 0.45
- financial - 0.65
- influence - 0.6
- legacy - 0.25
- management - 0.45
- model - 0.45
- operation - 0.5
- organisation - 0.35
- planning - 0.55
- politic - 0.65
- prospective - 0.35
- strategy - 0.45
- structure - 0.25
- system - 0.25
- trend - 0.15
- value - 0.25

5 Communication - Base -
- advantage - 0.15
- collaborative - 0.25
- communication - 0.55
- computer - 0.15
- concept - 0.25
- cost - 0.25
- culture - 0.2
- distributed - 0.45
- flow - 0.45
- human - 0.55
- influence - 0.55
- information - 0.65
- model - 0.25
- network - 0.55
- online - 0.25
- subsystem - 0.25
- technique - 0.25
- technology - 0.25
- theory - 0.25

6 Computer - Base -
- automatic - 0.67
- cost - 0.25
- order - 0.67
- processing - 0.8
- technology - 0.7

7 Data - Base -
- data - 0.78
- operation - 0.5
- structure - 0.7
- value - 0.38

8 Database - Base -
- access - 0.65
- data - 0.6
- decision-making - 0.3
- order - 0.7
- retrieval - 0.5
- storage - 0.55
- structure - 0.78
- transaction - 0.63

9 Decision - Critical -
- analysis - 0.6
- change - 0.48
- competence - 0.38
- confidence - 0.45
- cost - 0.78
- decision - 0.78
- decision-making - 0.78
- evaluation - 0.58
- experience - 0.38
- expert - 0.18
- information - 0.88
- opportunity - 0.28
- time - 0.48

10 Demand - Normal -
- collaborative - 0.23
- customer - 0.63
- economy - 0.43
- flow - 0.23
- global - 0.43
- management - 0.43
- product - 0.63
- time - 0.43
- trend - 0.73

11 Digital - Normal -
- automate - 0.5
- automatic - 0.5
- computer - 0.7
- data - 0.62
- database - 0.55
- intangible - 0.23
- legacy - 0.5
- online - 0.6
- processing - 0.3
- retrieval - 0.4
- storage - 0.52

12 Education - Base -
- application - 0.25
- assessment - 0.45
- change - 0.55
- collaborative - 0.55
- collective - 0.45
- communication - 0.35

competence - 0.35
culture - 0.65
expert - 0.65
human - 0.75
individual - 0.75
information - 0.62
training - 0.65
value - 0.45

13 Enterprise - Base -
company - 0.77
management - 0.76
structure - 0.24
system - 0.23
technology - 0.44
value - 0.56

14 Evaluation - Normal -
analysis - 0.37
assessment - 0.34
collaborative - 0.34
collective - 0.34
competence - 0.34
component - 0.34
data - 0.34
decision - 0.44
design - 0.34
diagnostic - 0.45
failure - 0.44
individual - 0.34
influence - 0.37
performance - 0.41
problem - 0.41
prospective - 0.47
trend - 0.41
value - 0.41

15 Human - Base -
competence - 0.3
customer - 0.43
decision-making - 0.44
education - 0.55
human - 0.7
individual - 0.7
politic - 0.45
training - 0.67
value - 0.55

16 Implementation - Normal
application - 0.55
change - 0.6
delay - 0.34
design - 0.65
development - 0.5
diagnostic - 0.45
failure - 0.45
lifecycle - 0.55
management - 0.65
method - 0.5
operation - 0.55
planning - 0.54
requirement - 0.51
subsystem - 0.53
system - 0.53

17 Information - Critical -
cost - 0.56
decision - 0.67
retrieval - 0.4
structure - 0.67
time - 0.56
value - 0.66

18 Information System - Critical -
access - 0.8
application - 0.5
automatic - 0.6
communication - 0.5
cooperation - 0.7
coordenation - 0.6
data - 0.71
database - 0.81
decis ion-making - 0.5
distributed - 0.65
information - 0.7
online - 0.5
processing - 0.45
retrieval - 0.52
transaction - 0.6

19 Interface - Normal -
computer - 0.56
human - 0.8
operation - 0.76
order - 0.34

20 Knowledge - Critical -
analysis - 0.56
assessment - 0.6
confidence - 0.51
culture - 0.36
decision - 0.79
decision-making - 0.76
diagnostic - 0.56
excellence - 0.66
experience - 0.72
human - 0.46
information - 0.56
order - 0.56
organisation - 0.76
perspective - 0.62
strategy - 0.61
theory - 0.56

21 Logistic - Normal -
management - 0.51
material - 0.65
operation - 0.67
planning - 0.5
time - 0.53
transaction - 0.49

22 Management - Critical -
analysis - 0.34
assessment - 0.4
control - 0.75
coordination - 0.77
decision-making - 0.65
economy - 0.45
influence - 0.3
management - 0.91
organisation - 0.66
perspective - 0.55
planning - 0.75
prospective - 0.55
time - 0.55
value - 0.34

23 Market - Normal -
no keyword elements

24 Marketing - Normal -
no keyword elements

25 Methodology - Normal -
no keyword elements

26 Need - Base -
no keyword elements

27 Network - Normal -
no keyword elements

28 Process - Base -
no keyword elements

29 Product - Normal -
no keyword elements

30 Production - Normal -
no keyword elements

31 Purchasing - Normal -
no keyword elements

32 Requirement - Base -
no keyword elements

33 Risk - Base -
no keyword elements

34 Service - Base -
no keyword elements

35 Society - Normal -
no keyword elements

36 Specification - Base -
no keyword elements

37 Success - Normal -
no keyword elements

38 System - Normal -
component - 0.49
lifecycle - 0.45
order - 0.27
structure - 0.24
subsystem - 0.59

39 Task - Normal -
account - 0.39
communication - 0.49
component - 0.39
cooperation - 0.5
coordination - 0.51
cost - 0.3
flow - 0.39
goal - 0.69
human - 0.59
individual - 0.49
operation - 0.59
order - 0.39
performance - 0.39
requirement - 0.39
training - 0.59
transaction - 0.61

40 Technology - Critical -
change - 0.34
lifecycle - 0.55
operation - 0.68
value - 0.78

41 Telecommunication -
Normal -
access - 0.45
application - 0.55
communication - 0.75
computer - 0.7
cost - 0.45
data - 0.65
distributed - 0.55
information - 0.56
network - 0.56
online - 0.71
technology - 0.45
transaction - 0.45

42 Tool - Normal -
application - 0.77
computer - 0.56
goal - 0.61
method - 0.7
operation - 0.6
performance - 0.43
technology - 0.75

43 User - Normal -
human - 0.78
operation - 0.65

44 Value - Critical -
advantage - 0.32
commitment - 0.34
competence - 0.36
confidence - 0.34
cooperation - 0.34
decision-making - 0.44
education - 0.47
evaluation - 0.44
excellence - 0.39
experience - 0.34
expert - 0.34
influence - 0.44
information - 0.32
opportunity - 0.56
performance - 0.34
training - 0.44
value - 0.74

45 Work - Base -
company - 0.45
competence - 0.45
decision - 0.42
education - 0.55
employee - 0.75
experience - 0.45
goal - 0.6
human - 0.65
individual - 0.65
information - 0.55
management - 0.45
network - 0.55
operation - 0.45
service - 0.75
training - 0.51

Appendix B

Evaluation materials

This appendix contains materials used in the ViDESK prototype evaluation. These materials include the questionnaires and the evaluation tasks checklist for the conducted experiments.

B.1 Pre experiment questionnaire

1 Sex:

M ____

F ____

2 Age:

________ (*number*)

3 Computer use expertise:

I have never used	1
I have used it a few times	2
Neutral	3
I use it regularly;	4
I am an expert;	5
I don't know	6

4 Theme expertise:

I have never heard about the theme	1
I have heard something about it	2
Neutral	3
The theme is familiar to me	4
I am an expert	5
I don't know	6

5 Degree:

Undergraduate studies	1
BSc degree, (4-5 years)	2
BSc degree, (3 years)	3
MSc degree	4
PhD degree	5
I don't know	6

B.2 Post-experiment questionnaire for experiment 1

1 How did you consider the task of constructing the structure?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

2 How did you consider the activity of derive the concepts?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

3 How did you consider the activity of derive the keywords for the concepts?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

4 How did you consider the activity of derive the rating for the keywords?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

5 How did you consider the resulting structure to be representative of an Information Management introduction?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

6 How did you consider the task of input the structure in the system?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

7 How did you consider the concept space visualisation while input the structure?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

8 How did you consider the concept space visualisation useful as a structure representation?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

9 How did you consider the concept space visualisation informative?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

10 How did you consider the structure informative?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

B.3 Experiment 2 task 2.1 checklist

1. Use the Information Management concept space and describe its meaning, by filling in the blanks belonging to complete sentence;

   S1 The represented Information Management Concept Space has ______ (*number*) concepts.

   S2 The concept INFORMATION has ______ (*number*) keywords, the most rated of which are _______________ and ________________ (*keyword names*)

   S3 The concept TASK is represented by a small sphere because ______________ ________________________ (*reason*)

   S4 The relation between concepts WORK and USER has a similarity degree of ______ (*percentage*)

   S5 There are __________ (*number*) relations with a degree of similarity between 75% and 100% in the Information Management Concept Space.

   S6 The total number of relations for the concept TASK is _______ (*number*). Is there any of these with a degree of similarity of more than 50%: _______ (*YES/NO*)
2. Relate all the concepts using the following three criteria: *information*, *management*, and *cost*. How many concepts satisfy all the three criteria ________ (*number*)
3. Choose the concept *Computer* and analyse its relation with all other concepts. Indicate how many relations on the level 50-75% exist: ________ (*number*).
4. Create a criteria space by choosing a set of criteria (at last two) that allows the *Knowledge* and *Enterprise* concepts to be related. Specify the chosen criteria: _________ , __________ , __________ (*criteria)*
5. Perform a search based on the *Information* concept. Indicate the number of returned results: _________ (*number*)
6. Perform a search based on the *management* criterion. Indicate the number of returned results: _________ (*number*)

B.4 Experiment 2 task 2.2 checklist

1. Give a textual description of the relationships for the concept *Human* in the Information Management structure
2. Propose two more concepts to be added to the Information Management structure

   Concept 1: ______________

   Concept 2: ______________
3. For one of the proposed concepts, give three keywords that could contribute to its characterisation

   Concept: ___________

   Keywords: _____________ , ______________ ; ______________
4. Propose one document reference that you find by performing a Concept search about Information Management. (choose one concept with existing results)

   Concept: ___________

   Document reference: ___________________________ position: _______
5. Is the structure related with the Information Management paper?

yes, and is complete	1
yes, but needs further development	2
neither yes or no	3
no, but can be corrected	4
no, is completely wrong	5
6. Can you develop a structure like the one presented for a given subject area in which you are expert _______ (yes/no), if yes, please give a brief example that includes three concepts. For one of the concepts give three keywords with their ratings.

B.5 Post-experiment questionnaire for experiment 2

1. How would you rate the structure in describing the Information Management theme?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

2. How do you rate the concept space visualisation for exploring the Information Management structure?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

3. How do you rate the criteria space visualisation for relating Information Management concepts?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

4. How do you rate the system support to access a data source?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

5. How do you rate the system use for learn about Information Management?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

6. How do you rate the system to support your ability to contribute with new concepts and keywords about Information Management?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

B.6 Experiment 3 first theme structure: Holidays (in Portuguese)

IR DE FÉRIAS

TRANSPORTE avião 0.8 barco 0.3 comboio 0.5 carro 0.6 pé 0.3	**LOCAL** nacional 0.7 estrangeiro 0.5 praia 0.4 campo 0.4	**CUSTO** moderado 0.4 dinheiro 0.4 sacrifício 0.6 cambio 0.4
COMPANHIA família 0.4 filhos 0.5 amigos 0.3	**DIVERSÃO** cultural 0.5 religião 0.3 monumentos 0.5 desporto 0.4	**COMPRAR** agência 0.3 operador 0.5 directo 0.6

B.7 Experiment 3 second theme structure: Information Management (in Portuguese)

GESTÃO DA INFORMAÇÃO

<table>
<tr><td>INFORMAÇÃO
dados 1.0
detalhe 0.7
oportunidade 0.7
precisão 0.7
relacionamentos 1.0</td><td>GESTÃO
estratégias 0.7
objectivos 1.0
planificação 0.7</td><td>RECOLHA
dados 0.5
estratégias 0.5
procedimentos 1.0
relacionamentos 0.5
triagem 0.7
validação 0.7</td></tr>
<tr><td colspan="2">PROCESSAMENTO
algoritmos 1.0
estratégias 0.7
procedimentos 0.7</td><td>ARMAZENAMENTO
dados 0.5
procedimentos 0.7
relacionamentos 0.5
suporte 1.0</td></tr>
<tr><td colspan="2">DISTRIBUIÇÃO
estratégias 0.7
procedimentos 1.0</td><td>QUALIDADE
detalhe 1.0
oportunidade 1.0
precisão 1.0</td></tr>
</table>

B.8 Experiment 3 task 3.1 checklist

Participate in the structure construction by proposing concept, keywords and keywords ratings to be included in the structure.

Use the system facilities to discuss and vote the proposals.

It is expected that each user can contribute with, at least two concepts and five keywords to the common structure.

Two different situations will be tested: using one existing structure and start with an empty structure.

Existing structure:

Concept 1:

Concept 2:

Keyword 1:

Keyword 2:

Keyword 3:

Keyword 4:

Keyword 5:

Empty structure:

Concept 1:

Concept 2:

Keyword 1:

Keyword 2:

Keyword 3:

Keyword 4:

Keyword 5:

B.9 Post-experiment questionnaire for experiment 3

1 How did you understand what the other participants were communicating?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

2 Were you able to contribute to the structure?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

3 Compared with the other participants, did you contribute to the structure?

much more	1
more	2
neutral	3
less	4
much less	5
don't know	6

4 How did you consider the task of creating the common structure?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

5 How did you find using the tool for collaborative construction of the structure?

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

6 How did you rate the resulting structure?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

7 Using the system was:

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

8 How do you rate the use of the concept space visualisation for exploring the structure?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

9 How do you rate the use of the criteria space visualisation for exploring the structure?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

10 How do you rate the information visualisation facility in the criteria space for analysing and accessing the data source?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

11 How did you find the 3D interactive visualisation as part of the system?

very helpful	1
quite helpful	2
neutral	3
quite unhelpful	4
very unhelpful	5
don't know	6

12 Communicating with the other participants was:

very easy	1
easy	2
neutral	3
difficult	4
very difficult	5
don't know	6

13 Did you learn anything new about the theme from using the system?

YES ______

NO ______

If YES, please specify:

Appendix C

Experimental data

This appendix analyses the data resulting from a set of three experiments conducted with the ViDESK prototype. The ViDESK prototype was intended to test both the functionality and the effectiveness of the use of the structure for knowledge sharing and the visualisation to support collaborative learning.

The three experiments are:

- **Experiment 1** focused on assessing how a particular knowledge theme can be represented by the structure, how the visualisation design can represent the structure and how the ViDESK prototype can be used to create the structure.
- **Experiment 2** focused on assessing how a user can understand the structure, how a user can individually learn from using the ViDESK system and how a user can be supported for accessing a data source.
- **Experiment 3** focused on assessing how users can share the structure, how users can enhance the structure and how users can learn collaboratively.

All three experiments involved 60 volunteers and more than 140 evaluation hours. The reported results are a selection of the available data and its organisation takes into account the evaluation requirements as presented in chapter 7 **– Experiments to evaluate the system in use**. Empirical results were considered following observation of users of the ViDESK prototype, the system logs and participants' questions, remarks and suggestions.

C.1 Reporting data from experiment 1: Construct a structure and its visualisation

This section presents the results from experiment 1 by reporting:

- The participants' group characteristics;

- The resulting structures specified by the participants for knowledge sharing;
- The resulting visualisations for representing the specified structures;
- The resulting data from the post-experiment questionnaire.

The structure for knowledge sharing and concept space visualisation are presented in detail in chapter 5 – **A model for a visualisation for knowledge sharing**.

PARTICIPANT GROUP CHARACTERISTICS

Each participant was able to specify a structure for knowledge sharing, representing his/her own view on his/her knowledge theme. There were 12 participants, i.e. six *Information Management* experts and six experts on a variety of different themes. Only four structures were specified in English (all from *Information Management*). The others were specified in Portuguese.

Table 21 presents the characteristics of the participants in experiment 1 for 12 structures. Future references to the participants will be made using the structure number in the first column.

Structure Number	Knowledge theme	Expert sex	Expert age	Computer expertise	Theme expertise	Degree
1	Information Management	M	37	Regular	Expert	PhD
2	Information Management	M	49	Regular	Expert	PhD
3	Information Management	M	34	Expert	Regular	MSc
4	Information Management	M	31	Expert	Regular	MSc
5	Dance	F	33	Little	Expert	MSc
6	Information Management	M	34	Expert	Regular	MSc
7	Bakery	M	30	Regular	Expert	BSc
8	Human Resources	M	40	Regular	Expert	MSc
9	Earth Sciences	F	30	Little	Regular	BSc
10	Football	M	29	Expert	Regular	MSc
11	Information Management	M	33	Expert	Regular	PhD
12	Mechatronics	M	36	Expert	Expert	MSc

Table 21: Participants characterisation for experiment 1

Some remarks can be made about the participants of experiment 1:

- The gender distribution of the participant was unbalanced, with ten male participants, which limited gender analysis.
- The participants' ages were between 29 to 49 years old. The average age for *Information Management* experts is 36.3 years. The other knowledge theme participants had an average age of 33 years old.
- When asked about their computer expertise, participants professed a regular or expert status. Only two participants admitted having little knowledge about computers, these two being the two women participants (who were also experts in themes other than *Information Management*).
- When asked about their theme expertise, all participants claimed to be expert or to have regular knowledge. Notice that these values of 50% of expert and 50% of regular responses were maintained for the *Information Management* participants and the other participants.

RESULTING STRUCTURES

Some of the characteristics of the specified structures for knowledge sharing have been analysed, as presented in Table 22:

- Number of concepts in the structure: as a total and distributed by concept type.
- Number of keywords: all the keywords in the structure, including the repeated ones. A second number gives the existing different keywords – all the non-repeated keywords.
- Number of keywords for each concept: with three values average, maximum and minimum.

structure number	Number of concepts				Number of keywords	Average keywords by concept	Maximum keywords by concept	Minimum keywords by concept
	Total	Critical	Base	Normal				
1	5	1	2	2	34 / 25	6,8	10	4
2	6	1	2	3	27 / 22	4,5	5	4
3	7	2	2	3	29 / 17	4,1	6	2
4	6	2	2	2	30 / 25	5,0	6	4
5	7	2	5	0	64 / 47	9,1	9	9
6	7	3	2	2	40 / 29	5,7	6	5
7	10	4	5	1	52 / 43	5,2	8	2
8	5	3	2	0	33 / 22	6,6	8	5
9	6	1	2	3	18 / 11	3,0	5	1
10	8	4	4	0	57 / 35	7,1	8	6
11	7	3	4	0	26 / 13	3,7	6	2
12	5	2	3	0	17 / 10	3,4	5	3

Table 22: Constructed structure characteristics

If we group each of the structures into two groups concerning the knowledge theme being represented, we obtain Table 23. The groupings are *Information Management* and all the other themes.

	Number of concepts	Number of keywords	Number of different keywords	Average keywords by concept	Maximum keywords by concept	Minimum keywords by concept
Inf. Manag. Structures	6,33	31,00	21,83	4,98	6,50	3,50
other structures	6,83	40,17	28,00	5,74	7,17	4,33
all the structures	6,58	35,58	24,92	5,36	6,83	3,92

Table 23: Structure average values for grouping themes

The structures tend to have a small number of concepts (between 5 to 10) with a total number of keywords in the structures that is 5-6 times greater than the number of the concepts (although values range from 3 to 9). Notice that within the same theme (*Information Management*) values tend to be more similar. Another interesting trend seems to be that the number of repeated keywords tends to decrease in structures with more concepts. The ratio of non-repeated keywords in the structure to the total number of keywords is a value in the range of 0.56 and 0.81, the medium value being 0.7; this value is the same regardless of theme grouping.

In addition to the reported data, Table 24 provides indicators compiled from the analysis of the expert's visualisations (concept spaces). As introduced in chapter 5, section 5.3 – the visualisation design – the links representing relationships between concepts are red links for strong relationships and blue links for upper medium relationships. The concept type is also colour coded. The critical type is red, the base type is blue, and the normal type is light blue.

Notice that the number of links is higher for structures related with themes other than *Information Management*. Also in the majority of the structures (10 out 12), were exists at least one isolated concept. The blue links tend to outnumber red links; the exceptions are two structures where red links represent all or all but one of the existing links (both structures refer to other themes).

structure. number	Number of links	Red links	Blue links	Number of concepts	Number of isolated concepts	Figure
1	4	2	2	5	1	1
2	1	0	1	6	4	2
3	4	0	4	7	2	3
4	2	1	1	6	2	4
5	3	0	3	7	1	5
6	1	0	1	7	5	6
7	8	7	1	10	3	7
8	5	0	3	5	0	8
9	7	7	0	6	0	9
10	5	4	1	8	3	10
11	3	1	2	7	4	11
12	1	0	1	5	3	12

Table 24: Structure visualisation characteristics

From the above table three interesting observations can be made:

- The average number of links for the *Information Management* structures is smaller when compared with other structures (2.4 against 4.67);
- Although the average number of blue links is similar for the *Information Management* and other structure groups, the medium number of red links is smaller for *Information Management* structures (0.6 against 2.33);
- The average number of isolated concepts is greater in the *Information Management* group (2.8 against 2.0).

RESULTING VISUALISATIONS

Based on each of the specified structures, each expert also produced the respective concept space visualisation. The following observations concern these visualisations. The figures present snapshots of the screen. Notice that the concept space visualisation is a virtual world that can be explored and navigated according to the users will, and thus there is no unique image for representing the structure.

The criteria for obtaining each concept space image was fitting all the structure's concepts into the computer window and obtaining the optimum angle to show all the existing links between concepts.

The structure visualisation (concept space) in figure 76 has the following features:

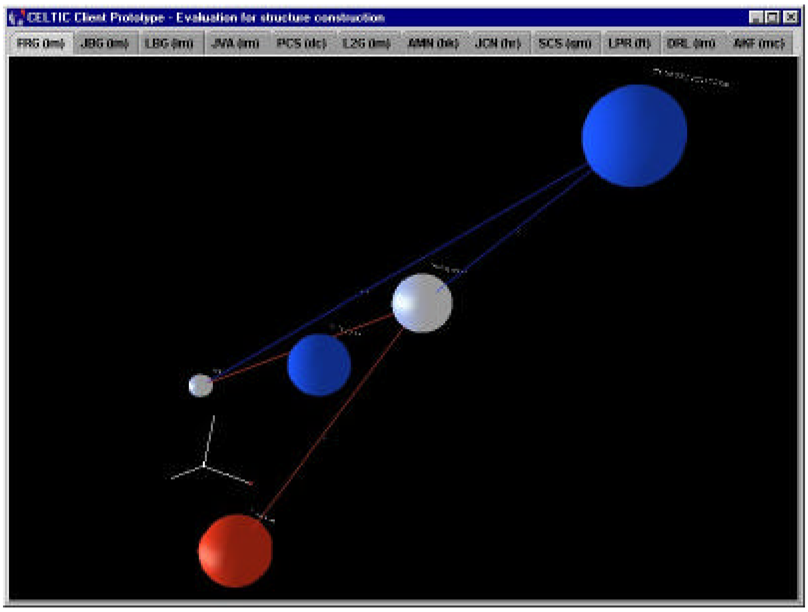

Figure 76: Structure 1 concept space visualisation view

- Strong link between the unique critical concept and a normal one;
- Strong link between the two existing normal concepts;
- One of the base concepts is not linked.
- The shape formed by the concepts is a dispersed cloud with the unique critical concept isolated.

The structure visualisation (concept space) in figure 77 has the following features:

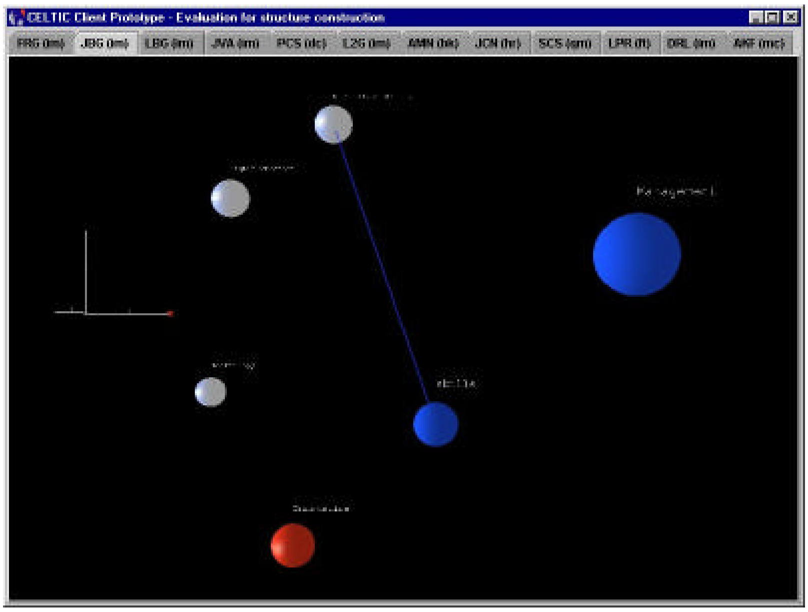

Figure 77: Structure 2 concept space visualisation view

- Upper medium link between normal and base concepts and the concepts form a "V" shape with the existing critical concept on its base.

The structure visualisation (concept space) in figure 78 has the following features:

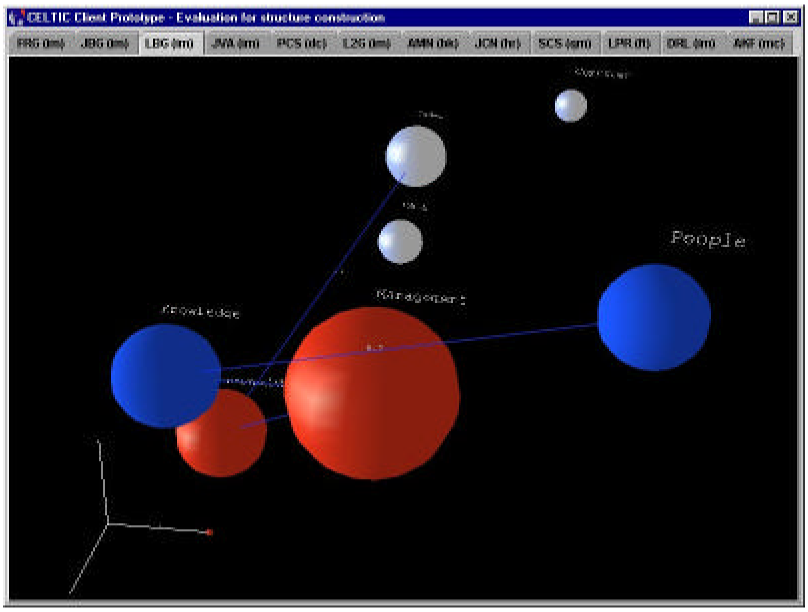

Figure 78: Structure 3 concept space visualisation view

- The critical concepts are linked: three of the four links include one of the two critical concepts.
- An upper medium link relates the unique base concept;
- The concepts form a two-group cloud with all the existing base concepts isolated.

The structure visualisation (concept space) in figure 79 has the following features:

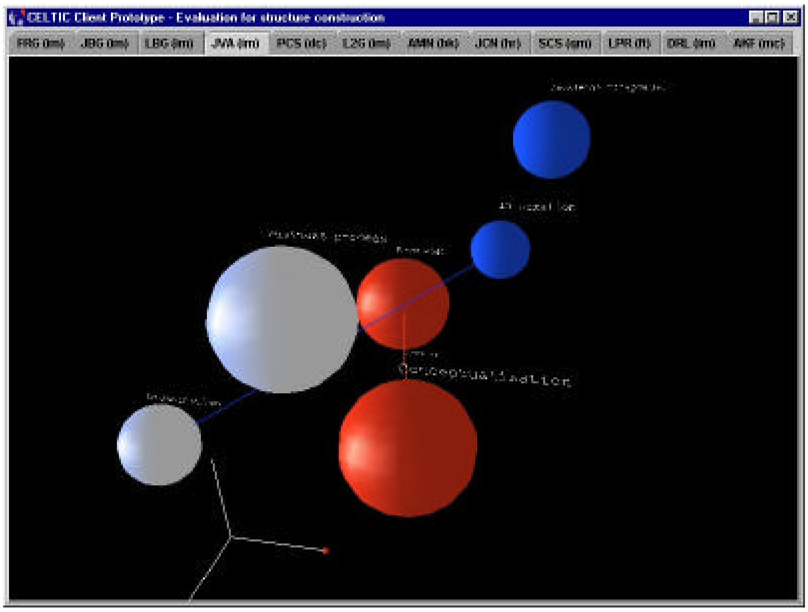

Figure 79: Structure 4 concept space visualisation view

- The two existing critical concepts are strongly linked.
- One upper medium link exists between a base and a normal concept;
- The concepts form a two-group cloud with all the existing base concepts isolated.

The structure visualisation (concept space) in figure 80 has the following features:

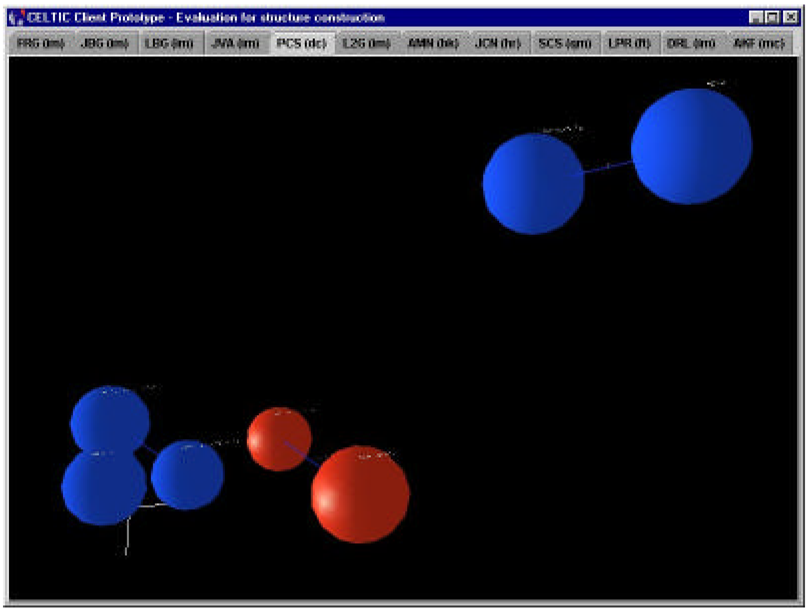

Figure 80: Structure 5 concept space visualisation view

- The two existing critical concepts are upper medium linked (corresponding to the blue lines – a level of semantic distance between 0.5 and 0.75);
- There are two more upper medium links between base concepts; The concepts form a two-group cloud shape with two linked base concepts isolated.

The structure visualisation (concept space) in figure 81 has the following features:

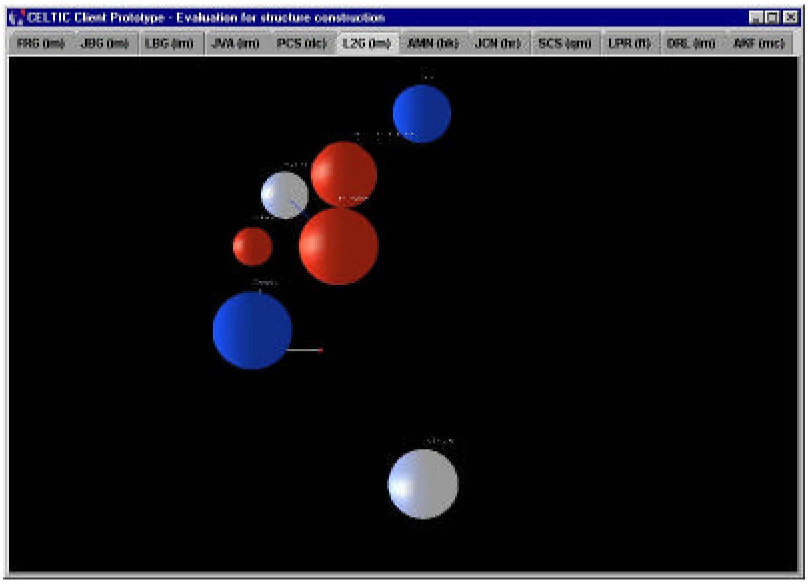

Figure 81: Structure 6 concept space visualisation view

- One upper medium link between a critical and a normal concept.
- The concepts form a cloud shape with one normal concept isolated.

The structure visualisation (concept space) in figure 82 has the following features:

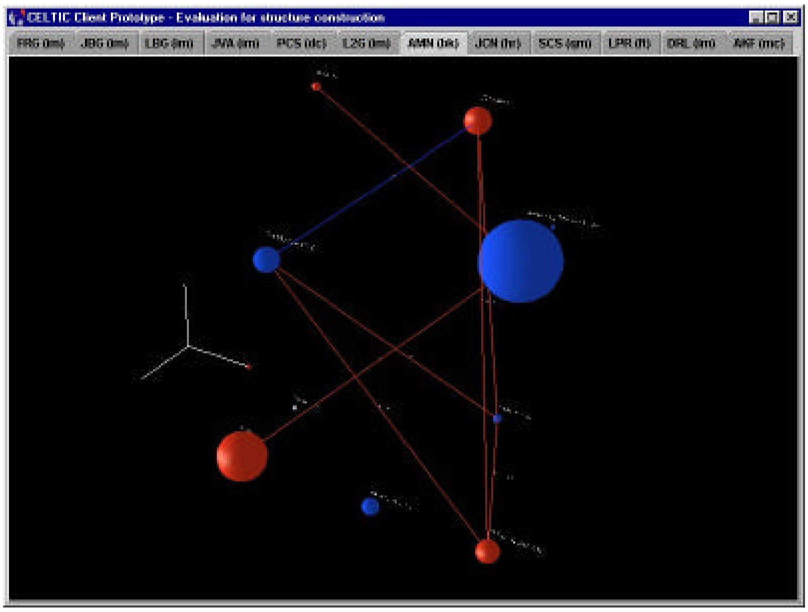

Figure 82: Structure 7 concept space visualisation view

- All four critical concepts are linked although none with other critical concepts.
- Only one upper medium link exists between a critical and a base concept;
- The concepts form a dispersed rectangular shape with crossing links.

The structure visualisation (concept space) in figure 83 has the following features:

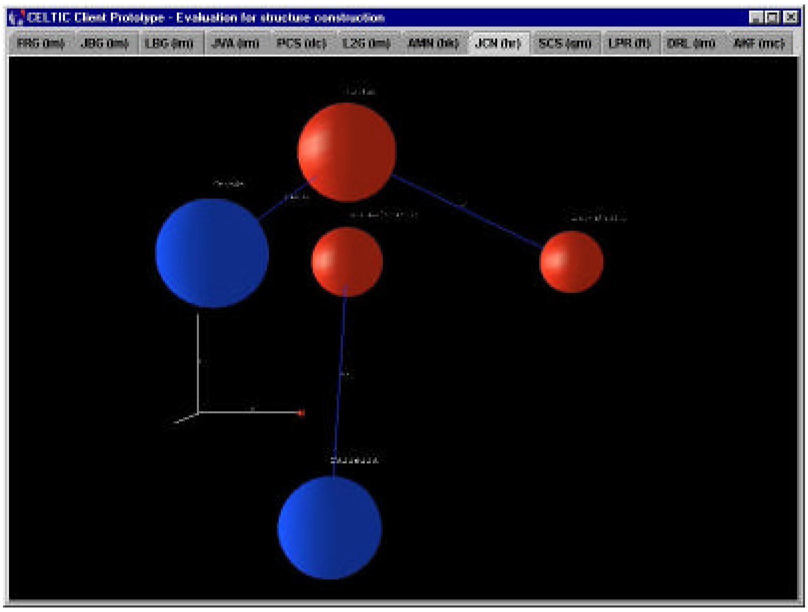

Figure 83: Structure 8 concept space visualisation view

- All five concepts are upper medium linked;
- The concepts form a cloud shape with all concepts close together.

The structure visualisation (concept space) in figure 84 has the following features:

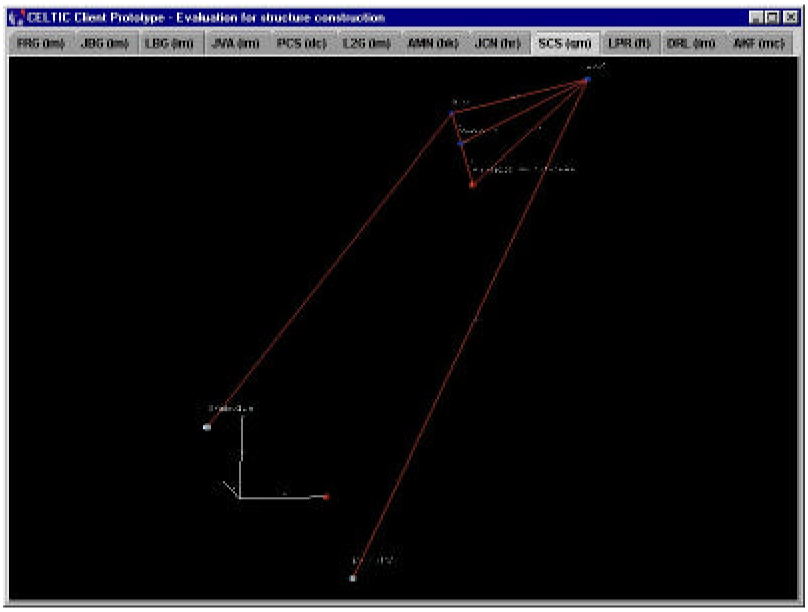

Figure 84: Structure 9 concept space visualisation view

- All six concepts are strongly linked;

- One base concept has four links, the other two base concepts have three links each, and all the concepts have at least one link;
- The concepts form an irregular shape with small spheres and two normal concepts located in two distinct isolated positions.

The structure visualisation (concept space) in figure 85 has the following features:

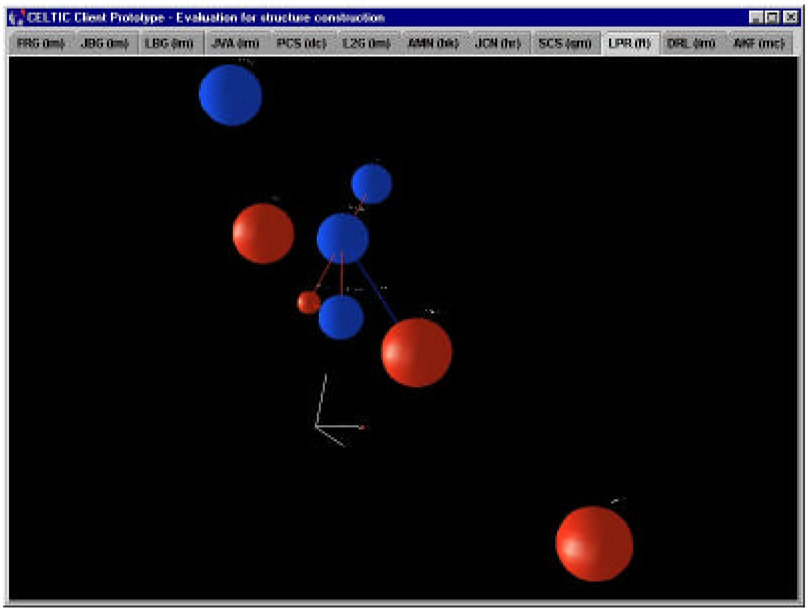

Figure 85: Structure 10 concept space visualisation view

- A critical concept has two strong links with base concepts;
- There are two isolated critical concepts;
- The concepts form a cloud shape with one critical concept isolated.

The structure visualisation (concept space) in figure 86 has the following features:

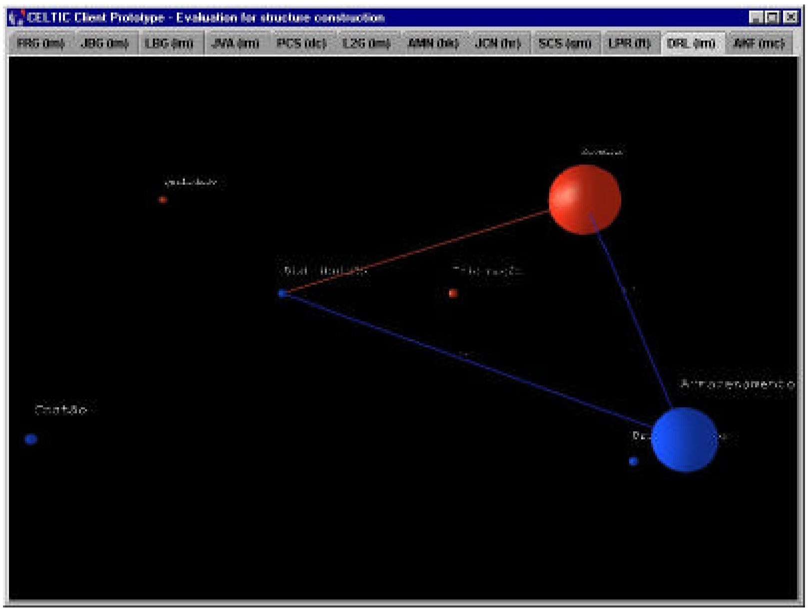

Figure 86: Structure 11 concept space visualisation view

- One strong link exists between a critical and a base concept;
- One blue link exists between a critical and a base concept;
- One upper medium link exists between base concepts;
- The concepts form a pyramid shape with two concepts in isolated positions: the links form a triangle. There are just two concepts (both triangle vertices) of the concept space that are not represented by small spheres indicating concepts with no or a small number of keywords elements.

The structure visualisation (concept space) in figure 87 has the following features:

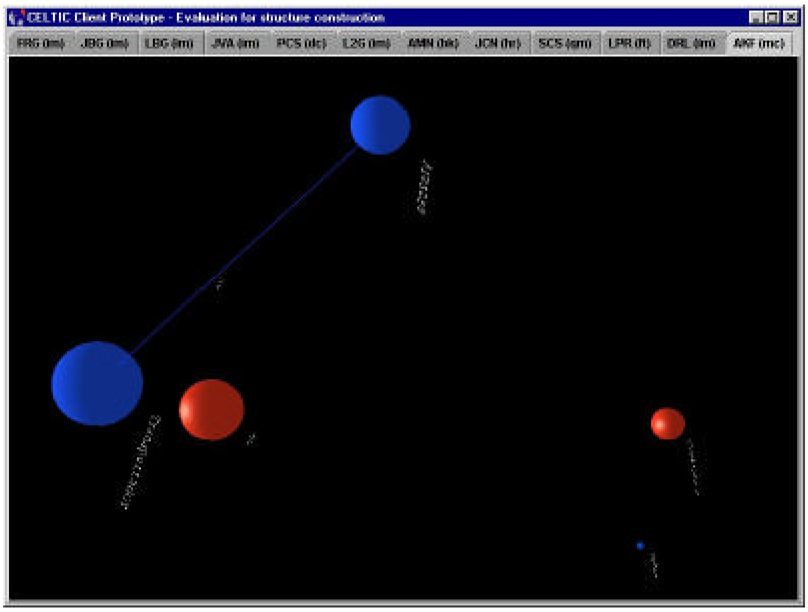

Figure 87: Structure 12 concept space visualisation view

- An upper medium link exists between two base concepts;
- The concepts form a dispersed cloud with two groups of two concepts and one more isolated concept linked to one of the existing groups.

From the above figures it should be noted that there are no unique or uniform visual rules for each expert to create his/her structure for knowledge sharing. Even for the same knowledge theme there seems to not exist general agreement in how each expert places concepts. Also, there is no common shape and link structure of the concepts between the different concept space visualisations. Both shape and concepts links seem to obey an internal logic of the expert. The concept space visualisation seems to be used as a way to further organise the structure for knowledge sharing.

POST-EXPERIMENT QUESTIONNAIRE

From the post-experiment questionnaire (appendix B.2) data about the ten questions have been collected and summarised as follows:

- The task of constructing a structure was found to be easy by 9 of the 12 participants. Among the six *Information Management* experts, 3 report it as a neutral (1) or difficult task (2).
- participants found easy the task to derive concepts for constructing the structure. One participant said it was neither easy nor difficult (*Information Management* expert) and others report it as a very easy task (*Mechatronics* expert).
- Deriving keywords for constructing the structure was considered very easy (1), easy (6), neutral (2), and difficult (3). These values indicate that deriving keywords is a more difficult activity when compared to deriving concepts. All the participants that reported it difficult were experts from themes other than *Information Management*.
- The keywords rating activity for constructing the structure was found very easy (2), easy (1), neutral (4), difficult (3), and very difficult (2). Overall, keyword rating was considered the most difficult task in the structure construction (when compared with the construction itself, derive concepts and derive keywords). Note that 4 out of 6 of the non-Information *Management* experts find keywords rating a very difficult or difficult task.
- When asked to rate the structure, 11 participants said that it is quite helpful. One participant (the *Earth Sciences* expert) though it quite unhelpful.
- Inputing the structure was very easy for 5 participants. Others responded easy (5), neutral (1), and one said it was very difficult (and stated that the system showed provide a spell checker and not make the user repeat the concept name when inputting each keyword).
- When asked about the facility of using the concept space visualisation while inputting the structure, participants referred to it as very helpful (2), quite helpful (8), and neutral (2).
- When asked if concept space visualisation was useful as a structure representation, participants considered it very helpful (5) and quite helpful (8).

- When asked if concept space visualisation was informative, participants considered it very helpful (2), quite helpful (8), neutral (1), and quite unhelpful (1).
- When asked if the structure was informative, participants considered it very helpful (2), quite helpful (8), neutral (1), and very unhelpful (1).

C.2 Reporting data from experiment 2: Explore a structure by navigating the visualisation

This section presents the results from experiment 2 by reporting:

- The participant group characteristics;
- The resulting data from participants' use of the structure visualisation
- The resulting data from participants' exploration of the structure content
- The resulting data from the post-experiment questionnaire

The structure for knowledge sharing, visualisation design and support for accessing a data source is presented in detail in chapter 5 **– A model for visualisation for knowledge sharing**. The structure for knowledge sharing is about *Information Management*.

PARTICIPANT GROUP CHARACTERISTICS

Five groups were considered: young people, mature people, undergraduate and graduate students and university staff. The total number of participants was 40 distributed by young people (4), mature people (4), undergraduates (10), graduates (11) and university staff (11). The following table resumes the medium values that characterise each group, taken from the pre-experiment questionnaire (appendix B.1).

Values for computer and theme expertise (*Information Management*) vary between 1 (no knowledge) to 5 (expert). The degree is codified as undergraduate studies BSc, MSc, and PhD. Notice that two BSc equivalent levels are considered once the Portuguese education system has degrees with 4 and 5 years

("*Licenciatura*") along with 3 years degrees ("*Bacharelato*"). This explains the score on the undergraduate group where some of the participants have already completed third year credits. Table 25 summarises the participants characteristics.

Group	**Sex**		**Medium age**	**Computer expertise**	**Theme expertise**	**Degree**
	M	**F**				
Young people	2	2	15,25	3,50	1,25	1,00
Mature people	4	0	54,25	3,25	2,50	1,50
Undergraduate	7	3	23,60	4,20	2,90	1,50
Graduate	7	4	31,45	3,55	2,82	2,09
University staff	9	2	34,36	4,18	3,91	4,00
TOTAL	**29**	**11**	**30,95**	**3,85**	**2,95**	**2,30**

Table 25: Experiment 2 participants groups characteristics

As expected, the average age for each group is greater for the mature people and smaller for the young people group. All the other groups follow a “natural order” being the undergraduate and graduate average ages equivalent to the normal average age to be in the third of a five-year course in Portugal. The university staff average age is the greatest among all the university groups.

There were twice as many males as females. In the mature people group there were no female participants and only the young group had a balanced number of males and females. Based on that population, the option was not to use the sex variable for data analysis.

Self-assessment ratings for expertise were asked of the participants based on their ability to use a computer and theme expertise. As expected, for computer expertise, the young group and the undergraduate group had higher scores than graduate and mature people groups indicating higher computer expertise. Their age and the relatively recent introduction of computers in Portuguese Universities (15 years) may have influenced this. The university staff were the exception, with a score that is closer to the score of undergraduates. Notice that undergraduate participants were chosen from a Computer Science major scheme.

PARTICIPANTS' USE OF THE STRUCTURE VISUALISATION

Experiment 2 consisted of two tasks as presented in section 7.3 – Experimental Methodology. The first task was related to using the visualisation to findout more about the structure for knowledge sharing. Appendix B.3 presents the task 2.1 checklist. Each participant had to complete this checklist while using the ViDESK prototype and fill the correct answers to obtain true sentences. There were a total of eleven sentences to be completed.

Group	**Group size**	**Number of correct answers (out of 11)**				
		7	**8**	**9**	**10**	**11**
Young people	4			1	2	1
Mature people	4		1			3
Undergraduate	10		1	1	1	7
Graduate	11	2		2		7
University staff	11		1		1	9
All groups	**40**	**2**	**3**	**4**	**4**	**27**
		5%	**7,5%**	**10%**	**10%**	**67,5%**

Table 26: Experiment 2, task 2.1 scores

From Table 26, some observations can be made:

- The number of participants that completed the task with all the eleven correct answers is 67,5%.
- Only two participants have four errors in task 2.1. Note that both participants are from the graduate group and both have little computer and theme expertise.
- The young group was the unique group that has more people with one or more errors than without errors.
- The more common errors come from the questions dealing with the criteria space, which was responsible for 12 of the 29 errors made by all the participants. The criteria space questions are questions 2 and 4 (appendix B.3).
- The young group participants made their errors on questions related to the criteria space (3 out the 4 errors reported).
- Only the young and graduate groups have an error rate greater than or equal to one error per participant (respectively 1.0 and 1.09).

- The university staff group presents the smaller error rate of 0.36 errors per participant, which is more or less half the value of the second best group (undergraduate group – 0.60).

PARTICIPANTS' EXPLORATION OF THE STRUCTURE CONTENT

The second task, 2.2, presented in section 7.3 – Experimental Methodology, concerns using the visualisation to explore the structure for knowledge sharing content. Appendix B.4 presents the task 2.2 checklist. Each participant must complete this checklist using the ViDESK prototype. A total of six questions constitute task 2.2.

The Table 27 summarises the data obtained from participant's answers.

- The first question concerns with the visualisation analysis: if the participant answers the question it was counted as yes, otherwise it counts as a no.
- The second and third questions are related to concept and keyword proposals made by each participant: for the concepts, participants proposed one or two entries and for the keywords, participants proposed one, two or three entries.
- The fourth question is related to the document chosen by each participant from the browser results displayed as result of a concept search, the order position in the results list was registered as first, second, third and other positions.
- Question five asks how the participants associate the structure for knowledge sharing with an article with four pages. The used article was: Butcher, D and Rowley, J. – *The 7 R's of Information Management, Managing Information*, March 1998 (vol. 5, n. 2), the registered number was the answer to a multiple choice question as presented in appendix B.4.
- The last question was to discover if the participant was able to develop a structure and to present the ratings for the keywords already proposed in the third question: the answer can be yes or no.

Questions	1		2		3			4				5					6	
Group	**Y**	**N**	**1**	**2**	**1**	**2**	**3**	**1**	**2**	**3**	**4+**	**1**	**2**	**3**	**4**	**?**	**Y**	**N**
Young people	1	3		4			4	2		1	1	1	1			2		4
Mature people	2	2	3	1			4	2	1	1		3	1				3	1
Undergraduate	5	5	3	7			10	6		3	1	2	7	1			8	2
Graduate	3	8	2	9			11	8		1	2	3	7		1		11	
University staff	7	4	1	10			11	6	3		2	3	7	1			11	
All groups	**18**	**22**	**9**	**31**	**0**	**0**	**40**	**24**	**4**	**6**	**6**	**12**	**23**	**2**	**1**	**2**	**33**	**7**

Table 27: Experiment 2, task 2.2 gathered data

Concerning experiment 2, task 2.2, on the basis of the data the following observations can be made:

- 18 participants were able to analyse the visualisation design to describe the structure for knowledge sharing but 22 participants did not answer the question.
- The majority of the participants were able to propose two additional concepts to the existing structure for knowledge sharing. 31 proposed two and the other 9 one concept.
- All the participants (40) were able to propose the requested three keywords for one of the concepts proposed.
- After performing a concept search, participants chose a document from a result list. For each participant, the position order in the list was recorded. 24 participants chose the first element in the list, 4 chose the second, 6 the third and other 6 chose different position greater than the third one.
- After reading the *Information Management* article and comparing it with the structure, 12 participants responded that the structure fully represents the article. 23 participants responded that although the structure is related to the article, it needs further development. 2 participants had a neutral opinion, and one answered that the structure does not represent the article but can be corrected. Two other participants (from the young group) did not know how to answer the question.
- When asked if they could develop a structure for a theme of their expertise, the majority of participants answered yes (33), against seven that answered no.

Based on the observation of the 18 participant's actions answering the first question on task 2.2 the activity list in Table 28 was compiled, showing the number of times each activity was performed by the participants.

Activity number	Activity	Occurrences
1	Analyse relations between concepts	16
2	Get the semantic distance (colour/value)	9
3	Get the concept type (colour)	9
4	Reason about the structure content	6
5	Count one concept relations	5
6	Use the criteria space	5
7	Analyse concept spatial position	5
8	Analyse concept size	4
9	Get concept keywords list	4
10	Get concept type (listing concept properties)	2

Table 28: Activity occurrences list for complete question 1 of task 2.2

After grouping activities into those in the concept space visualisation, those in the criteria space visualisation, and those that consult the structure for knowledge sharing, it is possible to say that occurrences of using the concept space visualisation were exactly four times more than consulting the structure. The Table 29 summarises the grouping of activities. Note that use of the criteria space visualisation occurred only twice, which may indicate that its usefulness was low, at least when compared with the two other groups. However, the action requested in question 1 from the task 2.2 checklist might not be suitable to encourage use of the criteria space, as there was no direct need to compare keywords available in the concept space.

Activity groups	Activities included	Sum of occurrences	Percentage of all occurrences
Use the concept space visualisation	1, 2, 3, 5, 7, 8	48	73,8%
Consult the structure	4, 9, 10	12	18,5%
Use the criteria space visualisation	6	5	7,7%

Table 29: Activities grouping for complete question 1 of task 2.2

This usage profile seems to indicate a strong use of the visualisation facilities to explore the structure for knowledge sharing – more than 80% of the actions performed by participants to answer question 1 of task 2.2.

Compiling the list of proposed concepts (question two of the task 2.2) a total of 71 concepts were proposed resulting in a list of 34 unique concepts, listed in Table 30 along with the number of participants that proposed each concept:

12	Organisation	2	Process	1	Innovation
5	Analysis	2	Services	1	Logistics
4	Market	2	Software	1	Mechanisms
4	Planning	2	View	1	People
3	Media	1	Communication	1	Resource
3	Quality	1	Cost	1	Responsibility
3	Structure	1	Decision	1	Role
3	Time	1	Development	1	Search
2	Co-ordination	1	E-commerce	1	Utility
2	Experience	1	Human relations	1	Workflow
2	Information system	1	Information flow		
2	Monitoring	1	Information technology		

Table 30: List of the proposed concepts in task 2.2

The analysis of 33 participant's answers for proposing keyword rates in question number six of the task 2.2 checklist yields the following observations:

- Participants posed two questions about how to rate the three keywords concerning question three of task 2.2. The first question, posed by 9 participants, asked if the sum of keyword rates was 1.0. The second question, posed by 2 participants, asked if some of the keywords was rated with a rating of 1.0.
- Analysing the keyword ratings proposed by each of the participants, it was possible to observe that in 18 situations, the keyword ratings are all different, situations where two of the three ratings were equal (8) and situations where all the three ratings were equal (7). In 29 situations, the three ratings were greater or equal to 0.5. In the other 4 situations all the weights were smaller than 0.5. Only one situation occurred where the sum of all the rating was less than 1.0. In six situations there is at least one rating of 1.0 among the three.

Results of observation of use of the ViDESK prototype for accomplishing the two tasks from experiment 2 are summarised as follows:

- Participants in general were able to navigate both visualisations to explore and relate the structured elements and answer task 1 with a small number of wrong answers (there were no participants with more than four errors out of eleven answers in task 2.1). Many participants completed task 1 without errors (27 out of 40).
- From observation, there were different navigation styles used in the concept space visualisation. After responding to each question, some participants performed a refresh visualisation to return to the initial reference point. Other participants used the zoom facility to get an overall view of the visualisation and then focused on particular sections of it. Others used the interactive facilities to display textual information about the structure (list concepts and list one-concept keywords) and to find clues to locate concepts, such as the concept type, since this is colour coded. There was also a participant that seemed to prefer an overall image of the visualisation and was able to go directly for the concepts necessary to complete task 2.1.
- Participants showed no difficulty in using the translation and zoom facilities but the majority became disoriented by the rotation facility. A high number of participants (34) chose to complete the task without using the rotation facility. An interesting point is that three participants who used to operate CAD applications were able to use the rotation facility without problems. Note that the computer used in experiment 2 was a laptop with an external 3-button mouse.
- One of the observed orientation cues for using the concept space was the spatial position indicating that the option for a fixed concept spatial position visualisation can help the user's orientation. The other orientation clue is the XYZ axis in the origin point of the visualisation (displayed in a central position in the concept space window when the visualisation is rendered for the first time or refreshed).

- A number of participants (5) reported some difficulty in using the concept size cue given in the concept space visualisation because they "*lost the notion of the size of a particular concept when changing perspective*".
- The mature persons group was able to navigate both visualisations (concept space and criteria space) and seemed to enjoy using the system (as post-experiment questionnaire results show). Also, two of their members were among the fastest people to complete task one. They were also able to understand the structure independently of their theme expertise.

Regarding understanding issues arising from ViDESK usage; a number of observations can be made as follows:

- When participants were asked to analyse the structure content some tended to formulate more complex reasoning to be confirmed by exploring the visualisation design. An example is "*… if exists a Human concept, and a human must work, so I can try to find some sort of relationship of the kind Human and Work (…) let's see if exists a concept for Work! (…) Excellent, I must now confirm the relation between the two.*"
- Two of the participants were not able to describe more than the visualisation perspective displayed on the monitor although they had already used the ViDESK prototype to explore the structure.
- After using the criteria space a number of participants (22) spent some time trying new criteria and using the criteria space visualisation. Most of them came from the mature people (3), graduate (8) and university staff (7) groups.
- The young people group was able to navigate the concept space visualisation but had many difficulties in using the criteria space system and understanding the structure for knowledge sharing.

Regarding contribution, several participants reported that for them it was more difficult to propose new concepts for an existing structure than it would be for a new one.

POST-EXPERIMENT QUESTIONNAIRE

Data from the post-experiment questionnaire (appendix B.5), composed of six questions, was collected and is summarised as follows:

- Participants rated the structure describing the *Information Management* theme as very helpful (21) and helpful (18). One participant did not know how to answer (from the young group).
- Participants rated the concept space visualisation for the *Information Management* structure as very helpful (25), helpful (10), neutral (4) and very unhelpful (1); this last answer came from a participant in the graduate group.
- Participants rated the criteria space visualisation for relating the *Information Management* concepts as very helpful (20), helpful (18), and quite unhelpful (2). The quite unhelpful answers came from the young group.
- Participants rated the system support for accessing a data source as very helpful (30), helpful (9) and neutral (1). This last response came from the graduate group.
- Participants rated the system as supporting learning about *Information Management* as very helpful (20), helpful (18), and neutral (2). The neutral responses came from the undergraduate group.
- Participants rated the system support for their ability to contribute with new concepts and keywords about *Information Management* as very helpful (23), helpful (13), and neutral (4). The neutral responses came from undergraduate (1), graduate (2), and staff (1) groups.

C.3 Reporting data from experiment 3: Enhance a structure by using the visualisation for shared interaction

This section presents the results from experiment 3 by describing:

- The participant group characteristics;
- The structures resulting from collaboration between group members;

- The paper and pen and ViDESK prototype support for collaboration;
- The resulting data from the post-experiment questionnaire.

The structure for knowledge sharing, the visualisation and the sharing issues dealing with the collaboration support are presented in detail in chapter 5 – **A model for a visualisation for knowledge sharing**.

Two structures for knowledge sharing were used to perform task 3.1 from experiment 3 as discussed in section 7.4.3. Appendix B.6 presents the experiment 3 first theme – *Holidays* – and appendix B.7 presents the experiment 3 second theme – *Information Management*. Both themes were specified in Portuguese order to foster participant collaboration.

Each participant was asked to contribute to the enhancement of a structure for knowledge sharing together with the other three participants. The experiment was repeated for the two different themes (*Holidays* and *Information Management*). For each theme a first run used an existing structure and a second run started with an empty structure.

PARTICIPANT GROUP CHARACTERISTICS

Two groups were considered:

- One group – manual group – used paper and pen to perform task 3.1. Each participant received a paper that described the structure for the knowledge theme and the experiment 3 task 3.1 checklist (appendix B.8). Each participant was responsible for maintaining the structure updated with all the new group contributions. All four participants were placed around a table.
- The second group – system group – used the networked version of the ViDESK prototype. The ViDESK prototype includes a voting tool and a chat systrem to allow participants to communicate (they were asked not to talk during the experiment). Each participant had access to the structure

for knowledge sharing using the visualisation facility in the ViDESK prototype.

Table 31 summarises the characteristics of the participants in the two groups. These values were taken from the pre-experiment questionnaire (appendix B.1). Values for computer and theme expertise (*Information Management*) vary between 1 (no knowledge) and 5 (expert). The degree is codified as undergraduate, BSc, MSc, and PhD.

Participant	Sex	Age	Computer expertise	Subject expertise	Degree
Manual group					
Participant 1.1	M	34	5	4	4
Participant 1.2	M	62	2	2	1
Participant 1.3	F	30	2	4	2
Participant 1.4	F	33	2	2	4
System group					
Participant 2.1	M	22	4	4	1
Participant 2.2	F	24	4	1	1
Participant 2.3	F	22	5	4	1
Participant 2.4	M	23	4	4	1

Table 31: Experiment 3 participants' characteristics

From the participant's characteristics table, the medium group values were calculated and are presented in the Table 32.

Group	Sex		Medium age	Computer expertise	Theme expertise	Degree
	M	F				
Manual group	2	2	39,75	2,75	3,0	2,75
System group	2	2	22,75	4,25	3,25	1,0
TOTAL	**4**	**4**	**31,25**	**3,85**	**2,95**	**2,30**

Table 32: Experiment 3 groups' characteristics

The number of male and female participants is balanced and equal for the two groups. The ages of the manual group are greater when compared with the system group, the difference move them ten years, part by because one of the participants in the manual group was 62. Although computer expertise was lower in the manual group this did not affect the experiment because the group did not need to use computers. The theme expertise (*Information Management*) was the same for the two groups. The degree denotes the most important difference between the two groups, with all the system group participants being undergraduates. For the manual group, two of the participants had a Masters degree, one had a BSc degree and another was an undergraduate.

RESULTING STRUCTURES

As a result of task 3.1, four structures for each group were constructed, based on two themes: *Holidays* and *Information Management*. Each of the themes was used first with an existing structure (described in appendix B.6 for the *Holidays* theme and in appendix B.7 for *Information Management*). After using an existing structure, the same theme was used again, but starting with an empty structure (a structure with zero concepts defined).

Some of the characteristics of the specified structures for knowledge sharing are as follows, and are summarised in Table 33:

- Number of concepts in the structure. The number of proposed concepts that were accepted by a majority of group members.
- Number of keywords. The number includes all the keywords, including repeated ones. A second number gives the existing different keywords.
- Number of keywords for each concept. Three values are considered: medium number of keywords by concept (given by the total number of keywords divided by the number of concepts), the maximum number of keywords that a concept in the structure has, and its minimum number.

	Number of concepts	Number of keywords	Medium keywords by concept	Maximum keywords by concept	Minimum keywords by concept
Existent structure s					
Holidays	6	23 / 23	3,8	5	3
Information Management	7	26 / 13	3,7	6	2
Manual group					
Holidays, existing structure	7	20 / 13	2,8	6	0
Holidays, empty structure	7	20 / 16	2,8	5	0
Information Management, existing structure	7	20 / 13	2,8	7	1
Information Management, empty structure	7	18 / 16	2,6	4	1
System group					
Holidays, existing structure	5	20 / 8	4,0	5	1
Holidays, empty structure	5	18 / 13	3,6	3	1
Information Management, existing structure	5	17 / 15	3,4	6	2
Information Management, empty structure	7	20 / 10	2,8	5	1

Table 33: Comparing structures from experiment 3 task 3.1

The resulting structures from collaboration between participants support the following observations:

- The structure contributions tend to be greater for the manual group, with six more concepts and five more keywords overall.

- The structure contributions for the system group present greater value of medium keywords by concept, for all the 4 structure situations.

- In two of the Holiday theme structure situations (existing and empty) the manual group proposed concepts without any associated keyword. The system group proposed at least one keyword for each proposed concept.

- The system group proposed more keywords for concepts with a minimum number of keywords and less keywords for concepts with a maximum number of keywords which seems to indicate a more distributed keyword contribution for all concepts by the system group.

- The structure Holidays (appendix B.6) had 23 keywords, which were unique. This means that there were no relations established between concepts. The manual group proposed 20 keywords, which include 7 existing keywords to establish new relations. The system group also proposed 20 keywords but with 12 existing keywords. A value, which represents 60% of the total keywords against 35% for the manual group.

- The structure Information Management (appendix B.7) has 26 keywords with 13 unique ones. The manual group proposed more than 20 keywords, which included 7 existing keywords. The system group proposed 17 keywords include 2 repeated ones. A value, which represent 11,7% of the total keywords against 60% for the manual group.

- From the last two observations above, it seems possible that the manual group treated both existing structures with different levels of concepts relationships in the same manner. The system group seems to take into consideration the existence of relationships between concepts for proposing new contributions.

- The empty structure for the Holiday theme had 20 keywords with 4 repeated ones (20%) for the manual group. The system group proposed 18 keywords that included 5 repeated (27,7%).

- The empty structure for the Information Management theme had 18 keywords with 2 repeated ones (11%) for the manual group. The system group proposed 20 keywords that include 10 repeated ones (50%).

- From the last two observations above, it seems possible to consider that the manual group has a focus on the contributions (both concepts and keywords) while the system group has a focus on the conceptual relationships.

- The empty structures in both groups, though created after using the existing structures, had many new elements which were different from those used in the proposed structure in appendix B.6, and B.7. In the manual group, the different concepts from the existing structures were

100% for the Holidays theme and 71.4% for the Information Management theme. In the system group, the different concepts from the existing structures were 80% for the Holidays theme and 85.7% for the Information Management theme.

COLLABORATION ACTIVITY

To accomplish task 3.1, participants from both groups had to perform collaborative and individual activities. The collaborative activity can be organised and considered for both groups according three general types: proposing, voting and discussion. The individual activity was note taking by participants in the manual group, while participants from the system group used the ViDESK prototype.

The proposing activity consists of individual proposals for enhancing the structure that can be add a concept, add a keyword, and alter a keyword rate. Table 34 summarises the proposing activity for the two groups.

	Holiday Structure	**Holiday empty structure**	**Information Management structure**	**Information Management empty structure**
Manual group				
Add concept	8	8	8	8
Add keyword	20	20	20	20
Alter keyword rate	0	2	0	1
System group				
Add concept	8	8	8	8
Add keyword	20	20	20	20
Alter keyword rate	3	4	2	6

Table 34: Proposing activity for the two groups, task 3.1

For each group four structures were considered, representing the themes *Holidays* and *Information Management* with two runs, the first using an existing structure and the second starting with an empty structure. Each participant was asked to propose for each of the four structures two concepts and five keywords. This means that the four group participants can propose 8 concepts and 20 keywords alltogether. Each participant can also, if desired, propose a new rate for an existing keyword with no restrictions.

The following observation can be made based on the Table 34:

- The values for add concept and add keyword were equal for the two groups and all the participants were able to propose the requested number of two concepts and five keywords per participant.

- The alteration keyword rates action had more occurrences when empty structures were used compared with existing structures.

- The system group proposed more alteration keyword rate actions than the manual group. In fact, the system group proposed five times more of these actions than the manual group. Even for each of the four structures the number of alter keyword ratings actions were greater in the system group.

Considering the voting activity, the manual group rejected 12 concepts and 2 keywords that were submitted for voting. Voting rejections tend to be done with lot of no votes. The voting of the system group resulted in 18 concepts and 5 keywords rejected. In all cases, voting generates discussion using the ViDESK chat facility.

For the discussion facility, in the manual group voting rejections generate little or no discussion and when it exists, it tends to be limited to ask for meaning and voting. In the system group, discussion tends to deal with concept relations and spatial positioning. Lacks of agreement entails more concept rejections when compared with the manual group. Also, rejections occur with minimum voting differences (with two participants in favour and two against).

The individual activity for the manual group – note taking – had two major observed issues: first, all four participants perform different actions with no common pattern, and second, the note taking had missing data among participants and most of it results from updating information in the structures (enhancing action).

The individual activity for the system group is supported by ViDESK visualisation use. The concept space visualisation was used by all the participants while the criteria space visualisation was used only by two of the participants (in the four structures). All the participants also used the ViDESK prototype to access the structure for knowledge sharing information. The chat facility was used for discussion after each new voting request. Voting tends to guide participants' interaction, if some voting is needed, participants tend to use other ViDESK facilities to know more and vote. Participants tend to return to using the visualisation only when a voting request occurs.

POST-EXPERIMENT QUESTIONNAIRE

Data from the post-experiment questionnaire was collected and summarised as follows. 8 questions for the manual group and 13 questions for the system group compose the post-experiment questionnaire (appendix B.9). Note that, as each group had two runs for task 3.1, the number of completed questionnaires was twice the number of participants (8 for each group, 16 in total).

- For understanding what the other participants were communicating, participants from the manual group respond that this was very easy (1), easy (6), and neutral (1). Participants from the system group responded very easy (4), easy (2), and neutral (2).

- When asked if they were able to contribute to the structure, participants from the manual group respond very easy (3), easy (4), and difficult (1). Participants from the system group respond very easy (1), easy (4), neutral (2), and difficult (1).

- When asked if, compared with other participants, they contributed to the structure, participants from the manual group responded much more (1), more (5), neutral (1), much less (1). Participants from the system group responded much more (1), more (4), neutral (2), and less (1).

- Considering the task of creating the common structure, participants from the manual group responded it was very easy (2), easy (5) and difficult (1). Participants from the system group responded very easy (3), easy (2), neutral (2), and difficult (1).

- Considering how easy to use participants find the tool for collaborative construction of the structure, participants from the manual group responded very easy (1), easy (6), and neutral (1). Participants from the system group responded easy (5), and neutral (3).

- When asked to rate the resulting structure, participants from the manual group responded it was very helpful (1), helpful (6), and neutral (1). Participants from the system group responded very helpful (2), helpful (4), and neutral (2).

- For the participants of the system group, using the ViDESK prototype was found to be very easy (1), easy (6), and difficult (1).

- For the system group, the use of the concept space visualisation for exploring the structure was considered very helpful (4), helpful (3), and neutral (1).

- For the system group, the use of the criteria space for exploring the structure was considered very helpful (2), and helpful (6).

- For the system group, the use of the information visualisation facility in the criteria space for analysing and accessing a data source was considered very helpful (1), helpful (4), and neutral (3).

- For the system group, the use of the 3D interactive visualisation as part of the system was considered very helpful (4), helpful (2), and neutral (2).

- Communicating with other participants was considered by the manual group participants to be very easy (4), easy (2), neutral (1), and difficult (1). Participants from the system group responded that it was very easy (1), easy (5), neutral (1), and difficult (1).

- When asked if they learned anything about the structure's theme, participants from the manual group responded yes (7) and no (1). Participants from the system group responded yes (6) and no (2).