Design, Development and Evaluation of a 3D Web-Based Prototype

By

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PREFACE

This thesis is about designing, developing and evaluating a 3D web-based prototype to facilitate the learning of abstract concepts within the natural science curriculum for the 10^{th} grade. This work is divided into several parts. First, the background is presented giving an insight of what motivated this project. Thereafter, a theoretical framework is discussed in details for designing and developing web-based leaning environments. A discussion of some developing models is taken, and the chosen design model is explained in details; followed by a detailed description of how all the steps of the planning, design and development phases were applied for producing the 3D web-based prototype (henceforth: 3D prototype). An evaluation section is dedicated to present the evaluation methods, results and data analysis. At the end, a discussion of some suggested improvements and conclusions are presented.

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Prototype's URL:
http://submission.intermedia.uib.no/~betzy/prototype/index.html

APPENDIX

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1 Motivation

During the spring semester of 2003 and while taking the course of pedagogical information science, two fellow students and I wrote two papers about evaluating, designing and implementing web-based 3D learning environments (Louis, Breien & Reigstad, 2003). We discovered that in recent years there was a growing interest in the development of 3D virtual learning environments with the use of avatars and chat functionality on the Web, for instance, Active Worlds [1a], Active Worlds Educational Universe [1b] and EduAction [2].

The work I did during the spring semester while taking the course of pedagogical information science, motivated me to write a thesis about a 3D web-based learning environment. Another source of motivation was the course I took in Human Computer Interaction. During this latter course I learned the important techniques of how to design and evaluate a system.

2 Introduction

The purpose of this project is to design, develop and evaluate a 3D web-based prototype that will facilitate the learning of abstract concepts within the natural science curriculum for the 10^{th} grade. The 3D prototype will be deployed at a Norwegian school near Bergen, Norway. The visual impact of 3D objects and the navigation possibilities that 3D technologies offer are excellent pedagogical tools for learning abstract scientific concepts.

This thesis has two main goals:

1. To design and develop a 3D web-based prototype using methods for developing multimedia-learning programs
2. To evaluate the 3D prototype doing a formative evaluation where an expert review and a usability test with middle school's teachers and students will be carried out. The formative evaluation will help to identify design and usability problems

This thesis is divided in two main parts. Part 1 discusses the planning, design and development phases of the 3D prototype, while part 2 discusses the evaluation of the 3D prototype, the analysis of the evaluation results and a final discussion.

Before embarking on these sections, however, a brief discussion of the history of Information and Communication Technologies (ICT) in education, as well as a discussion of instructional technology and the emergence of Computer Supported Collaborative Learning (CSCL) is presented.

3 Instructional Technology

There are many methods of instruction such as traditional classroom, video, radio and television, but none of these methods are classified as instructional technology, which is classified here as computer-based instruction. Before starting a discussion about 3D learning environments, a brief review of how instructional technology has undergone several changes through decades will be presented first.

It is important to distinguish between computer based learning systems and educational learning theories upon which they are based. Timothy Koschmann (1996) classified computer based learning system according to four paradigms.
The four paradigms identified by Koschmann are: 1.Computer Assisted Instruction (CAI), 2.Intelligent Tutoring Systems (ITS), 3.Logo-as Latin and 4.Computer Supported Collaborative Learning (CSCL)

Computer Assisted Instruction (CAI)
The paradigm of CAI emerged from the advent of courseware building tools in the 1960s that made it possible to develop computer-based aids for instructional purposes. The underlying learning theory applied by this paradigm was behaviourism, where instruction was seen as a process of transmission or delivery and learning was seen as the passive acquisition or absorption of an established body of information where the teacher is the final authority. The applications developed under this paradigm focused on identifying learning goals and implementing these in the applications by decomposing the goals into component tasks and by developing a sequence of activities that leads the learner through the whole subject domain. Research under this paradigm focused on instructional efficacy (Koschmann, 1996).

Intelligent Tutoring Systems (ITS)
This paradigm emerged in the 1970s and was rooted in the files of artificial intelligence.
Artificial intelligence focuses on the process of cognition as a computational process that can be studied through the construction of mechanically aware systems. The instructional applications developed under this paradigm were designed to assume the role of a skilled teacher. In other words, these applications were designed to provide every student with a personal tutor. The underlying theory is cognitivism. Instruction consists of activities designed to facilitate the acquisition of knowledge. The applications were designed to pose a problem with interactive feedback to the learner. The research focus for this paradigm is on instructional competence rather than instructional efficacy (Koschmann, 1996).

Logo-as-Latin Paradigm
This paradigm emerged in the 1980s, and had its basis in constructivism that earlier originated in the work of Piaget (1976). Learning is viewed as the process in which new information interacts with prior knowledge through a process of assimilation and accommodation.
The applications designed under this paradigm focused on letting the learners teach the computers, so that learners assume the role of the teacher. The learners engaged in programming activities such as designing and building programs, with emphasis on the use of Logo, a programming language designed for young children by Wally Feurzeig in the mid-1960s. The research focus for this paradigm is on instructional transfer and on learning to program in the service of more general educational objectives (Koschmann, 1996).

Computer Supported Collaborative Learning (CSCL)
In 1996 Koschmann introduced a new paradigm of educational technology called CSCL, (Koschmann, 1996). CSCL arose from research on Computer-Supported Cooperative Work (CSCW), which consisted of computer-based network systems called groupware that supported group work for a common task. According to Lipponen (2002), CSCL is focused on how collaborative learning supported by technology can enhance peer interaction and work

in groups, and how collaboration and technology facilitate sharing and distributing of knowledge and expertise among community members.
This new paradigm was built upon anthropology, sociology, linguistics, and communication science disciplines. For this reasons, CSCL research is grounded on different concepts of learning, pedagogy and research methodology than the previously discussed paradigms ((CAI), (ITS) and Logo-as-Latin). CSCL focuses on the use of technology as a mediation tool within collaborative methods of instructions (Koschmann, 1996). The underlying theory in which CSCL is built upon is influenced by socially oriented sciences such as constructivism, Soviet sociocultural theories and situated cognition. CSCL works tend to focus on process rather than outcome and in collaboration in order to facilitate learning. CSCL work has an interest in understanding the process from a participant's viewpoint, therefore, a focus on participant's talk, the artefacts that support and are produced by a team of learners, and the participant's own accounts of their work.

According to Koschmann, CSCL applications assume a variety of forms, and they can be categorised in a variety of dimensions, including the locus of use, how the use is coordinated in time, and the instructional role it was designed to serve. For instance, the locus of use may be intra-, inter- or extra–classroom, within the classroom, or across classrooms. With respect to time, CSCL applications can support synchronous or asynchronous interaction. Finally, the instructional roles of CSCL applications may vary from mediating communication within and across classrooms, introducing new resources into the classroom, and supporting knowledge building (Koschmann, 1996).

The model of instruction underlying CSCL is termed "collaborative learning"
There is no precise definition of the term 'collaborative learning'; and the definition provided here is one that is based upon a review of a variety of approaches to 'collaborative learning' discussed by Pierre Dillenbourg (1999).

Dillenbourg (1999) views collaborative learning in three dimensions: The scales of the collaborative situations (group size and time span), what is referred to as 'learning' and what is referred to as 'collaboration'.
Briefly, the first dimension (the scale of the collaborative situations) refers to the scale or group size that may vary from 2 to more subjects and the time they spent collaborating; time may also vary from minutes to hours or one year. Dillenbourg discusses different implications that involves collaboration between small groups, group memory and group dialogue.
The second dimension referred to as 'learning', discuses the different meanings of learning. Learning is expected to occur as a side effect of problem solving, measured by the elicitation of new knowledge or by the improvement of problem solving performance (Dillenbourg, 1999). Within some theories, learning is viewed as a biological process; and in education, learning is viewed as a cultural process, which occurs over years.

Dillenbourg (1999) discusses the third dimension (i.e. collaboration) as follows:

> "Collaborative learning is it a pedagogical method or a psychological process? The pedagogical sense is prescriptive: one asks two or more people to collaborate because it is expected that they will thereby learn efficiently. The psychological sense is descriptive: two or more people have learned and collaboration is viewed as the mechanisms, which caused learning".

Dillenbourg (1999) goes on to define collaborative learning as: “a *situation* in which particular forms of *interaction* among people are expected to occur, which would trigger *learning mechanisms*”.
A *situation* can be characterised as more or less collaborative when it occurs between people with a similar status within their community, have common goals, and to some extent have the same level of knowledge. For instance, collaboration is more likely to occur between pupils rather than between a teacher and a pupil or between a boss and her/his employee.
Interactions between the group members can be more or less collaborative if they focus on negotiation between the group members rather than giving instructions or imposing one’s view upon other group’s members.
Learning mechanisms involved in collaborative learning must be those that operate in the case of individual cognition, since there are still individual agents involved in group’s interactions.

3.1 **3D Learning Environments**

3D learning environments are a form of Virtual Reality (VR), which has been made possible by the advent of fast high-performance computer processing and graphics. VR falls into three categories: 1.text-based, 2.desktop VR and 3.immersive VR. The text-based category also called Multi-User Domains (MUDs) a user is allowed to specify an icon or image, which becomes an avatar within the virtual world or page and users can initiate text-based conversations. In immersive VR, a virtual world is simulated and users are required to use goggles and data gloves to manipulated objects in the virtual world. In Desktop VR, images are presented on a pc-screen and manipulated using the mouse or the keyboard. This form of desktop VR has become available to many through Virtual Reality Modelling Language (VRML), which allows virtual worlds to be distributed over the Web and integrated with other web-based programs (Dix *et al*., 1997).

The term Virtual-learning environment is used today to categorise any Internet or web-based learning resource, with associated discussion tools, while the term 3D learning environments is used to encompass a particular type of virtual environment that makes use of a 3D model (Dalgarno *et al*., 2002).

According to Dalgarno et al. (2002) the main characteristics of 3D environments are:

- The environment is built using 3D vector geometry, objects are represented using x, y and z coordinates describing their shape and position in 3D space
- The user’s view of the environment is rendered dynamically according to their current position in 3D space, meaning that users move freely in space and their view is updated as they move
- Objects within the environment respond to user action, for instance, information may be displayed when an object is selected with a mouse, or audio may be played when approaching an object or a particular location within the environment
- Some environments include 3D audio, which is audio that appears to be emitted from a source at a particular location within the environment. The volume of sound depends on the position and orientation of the user within the environment

The main focus of this thesis is on the use of 3D learning environments in web-based desktop VR.

3.2 **CSCL in 3D Learning Environments**

Collaboration on the Internet has its origin in the 1980s with the advent of MUD's (Multi-User Domains). These environments were based on computer-supported games and allow synchronous interaction between users, thus contributing to the development of virtual communities on the Internet (Galea *et al*., 2002). The incorporation of scripting languages allowed the extension of MUD's that originated a new type of environments called MOOs (Multi-user object oriented) where users could now manipulate objects freely. In recent years, Information and Communication Technologies (ICT) areas had developed towards the introduction of distributed learning by means of the use of advanced communication and multimedia services. Good communication infrastructures such as broad bandwidth Internet connections and advances in desktop computer graphics and processing power allowed the use of more sophisticated applications such as 3D learning environments.

Most of the existing 3D learning environments available today have been developed for military training or medical purposes. However, some of the available 3D learning environments have been developed for the learning of natural science and are available on the Internet. Many of these web-based applications are developed using VRML. 3D learning environments have not yet being widely adopted by middle schools. The reason for this slow implementation may be outdated hardware and lack of high-speed access to the Internet. Another reason is that 3D environments are expensive to develop and require above average programming abilities.

According to Galea et al. (2002), most 3D learning environments can be framed under the constructivist learning model and situated learning, since learners are active participants in the learning process by building their own cognitive structures.

3D learning environments might be useful when teaching and visualizing certain abstract scientific concepts. Learning through 3D environments enables a number of simultaneous activities that can influence the learning process, for instance:

- Manipulation and exploration of 3D objects

The visual aspect of 3D objects may help to manipulate and visualise objects from various perspectives that may be compared with real life experience. It is even possible to magnify 3D objects that are not visible to the human eye, for instance, small molecules, DNA and atoms.

- Navigation through space

Most 3D learning environments include a sort of icon or figure called avatar that represents users in the 3D space. An avatar can have a human appearance or any other kind of object. By using avatars, students can navigate freely through the virtual world and even be able to immerse avatars into 3D objects thus experiencing not only from the outside but from within an object.

- Communication and information

3D learning environments might include a set of tools in order to facilitate leaning. For instance:

Information tools: Such as videostreaming, 3D-audio and universal resource locator (URL) navigation can be used to present information.

Communication tools: Such as chat functionality, which enables users to discuss aspects related to the learning objectives in real time.

It is easy to navigate and interact in 3D virtual environments, once students have learned how to navigate and chat through an avatar, the students can interact with objects, explore an object, or reflect and analyse an object and the information attached to it.

3D learning environments and VRML offer visualization and immersion experiences that are not possible with traditional 2D-based media.
The visual aspect of 3D objects and the navigation possibilities that 3D technology offer facilitate the learning of abstract scientific concepts such as molecular structures, atomic bonding and DNA interactions, among others. For instance, by manipulating a 3D VRML model of a molecule students may have a richer experience of an object that is otherwise abstract.
Learning natural science at middle school has often been a challenge for many students. Scientific abstract concepts may be more difficult to understand and grasp by middle graders students because most early adolescents have not yet developed the ability to think on an abstract level. Abstract concepts should be taught through the use of supplementary materials and concrete examples (Ausubel, 1968).

In recent years there has been a growing interest in developing 3D learning environments on the Web for educational purposes. The following section presents some examples of 3D learning environments available on the Web, such as Active Worlds Educational Universe (Chemeet World) [1c], Education [2] and (CSU) Virtual Chemistry Laboratory [3].

3.3 **Related Work**

3.3.1 Active Worlds Educational Universe (AWEDU)

Active World Educational Universe (AWEDU) is an educational community based on VR technology on the Web. VR technology is based on a computer simulation of real or imaginary 3D world that enables a user to perform operations on the simulated world. The effects are shown in real time. Within these educational environments users can chat and interact with each other through avatars. In this educational community participants can enter a class, perform experiments, participate in discussions, and assist conferences or meetings. The members of AWEDU vary from teachers, students to experts.

The virtual environments developed by AWEDU support learning of art, language, science, history, among other subjects, and the teaching levels vary from secondary school to university levels. In spite of the possibilities that 3D virtual learning environments may offer, this type of web-base technology has not yet been taken widely into use by middle schools.

AWEDU offers the following functionalities:

- **Avatars**

In AWEDU, users are represented as 3D avatars. An avatar is the representation of a participant in virtual space. As participants move around in virtual space, their avatars move correspondingly. Avatars often move in a lifelike manner as they walk around, or even when they are standing in place. Avatars also typically have one or several gestures they can perform, thus one can approach another avatar within the virtual world, initiate a chat or explore worlds together. Most worlds have both male and female avatars as well as non-human avatars

Figure 1 Avatars

- **Building**

In order to build 3D worlds, it is necessary to become a citizen of AWEDU. As a tourist, one is only allowed to look, and the participation possibilities are very limited. Figure 2 shows an example of building a sign with a message on it

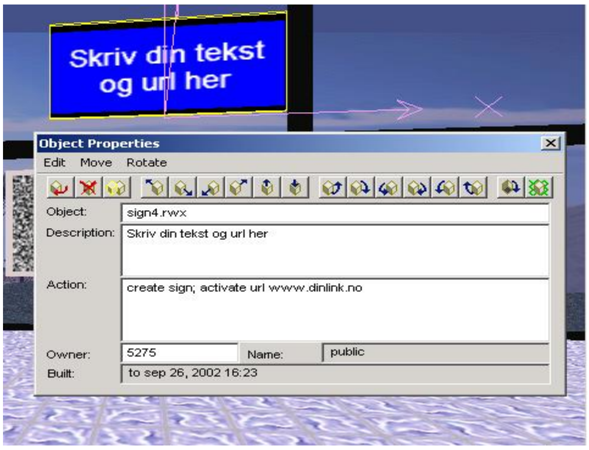


Figure 2 Building 3D objects

- **Chat**

One of the most important features in AWEDU is the possibility to establish synchronous communication chat with other people. There are a variety of chat functions, for instance; teleporting, making lists and messaging, whispering to another avatar, or just chatting to a whole class

- **Tutorials Lectures and Seminars**

Inside a 3D world one can also click on the signs, and a web page will appear in the right hand side of the screen in the integrated web browser. Usually this web browser contains a lot of information, forum discussions, seminars and tutorials about different topics. It is possible to see live lectures with a whole class chatting and participating in a lecture

AWEDU Browser

In order to visit Active World Educational Universe it is necessary to have the AWEDU browser installed.

The browser allows navigation in virtual worlds. It has four main windows as shown in Figure 3 below.

Figure 3 **The AWEDU Browser (Chemeet World)**

- The main window (Figure 3: 1)

The main window shows the chosen 3D world. In order to navigate in a 3D world, one has to choose an avatar. There are different visibility options for the avatars; for instance, one can choose to see the avatar or just to navigate without seeing it (third or first person view)

- The chat window (Figure 3:2)

The chat window enables communication with other AWEDU users in synchronous time. In this window messages from all users who are navigating the specific world are displayed

- The tab window (Figure 3:3)

The tab window displays different tabs with useful information: for instance, it shows all worlds running in the current universe, and how many visitors a world have. An "earth" globe points to the current world. A blue and purple light means the world is open to the public; a grey light means it is only open to selected users

- The web window (Figure 3:4)

The Web window displays web pages that are integrated to the 3D world in use. These pages can contain information that helps to navigate in the chosen world. Another important feature is that 3D world's objects are linked to web pages that are displayed in the web window with relevant information about the chosen object

The AWEDU Chemeet 3D world (see Figure 3), relates to the subject of chemistry and biochemistry for undergraduate college students and it uses the Chime plug-in to show 3D models of molecules. Inside this world students can interact with objects and simulate chemical experiments. This world is very closely related to this project, even though the content is for college students, not for middle school students.

3.3.1 EduAction

EduAction is a research project for developing web-based 3D virtual environments for natural science subjects. The main focus is to study how these 3D environments can stimulate active participation and collaboration. In these environments students can interact with other people through avatars, and construct and manipulate objects directly. The 3D environment combines multi-user 3D-graphics and Internet-based information retrieval. This application provides insight into the basic chemistry of a DNA molecule.

The focus of the EduAction project is to study the potential for using distributed virtual reality in collaborative learning from a pedagogical point of view. It is based on a networked 3D-application in which students from middle school (age 14) can collaborate in a virtual environment.

EduAction topics relates to the basic characteristics of the DNA molecule and gene technology. The 3D environment developed is called Mission Queen Maud's Land. The scenario of the application is a research laboratory in Antarctica. Here the students are represented in the virtual environment by an avatar. Each avatar has a role as a researcher and as a part of the research team of the Human Genome project.
The student's task is to find the sequence of a human DNA molecule. Students can navigate in the 3D-world and move, build and interact with 3D objects, as well as immerse the avatars inside human cells. Inside the 3D world there are necessary tools and molecular components to construct, rebuild, and repair both DNA molecules and proteins. Figure 4 shows the laboratory in the 3D world Antarctica.

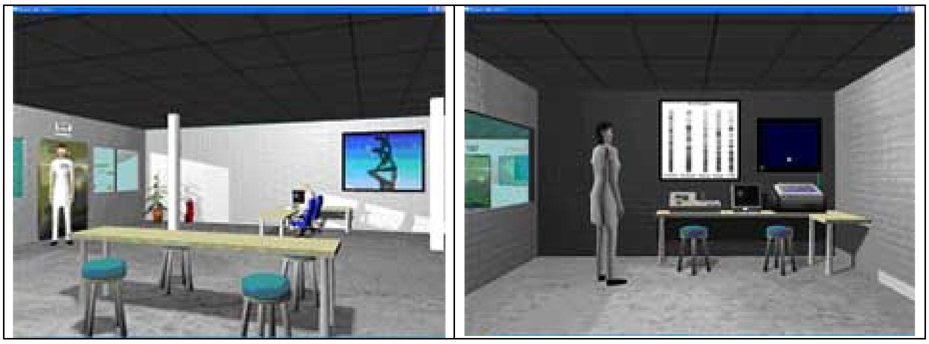


Figure 4 **Queen Maud's land laboratory**

3.3.2 The CSU Virtual Chemistry Laboratory

The Charles Sturt University Virtual Chemistry Laboratory (CSU) is a model of a chemistry laboratory. CSU has been developed using the VRML and it is available via a web interface. Within this virtual laboratory, learners can explore and manipulate items. Items can also be selected to display a web page with information about its use. The initial version was designed to allow learners to become familiar with the layout of the real laboratory as well as to find information about procedures when using the laboratory.

CSU allows the learner to access information about introductory chemistry. This 3D learning environment has a set of menus to allow the learners to choose a particular position within the environment and to carry out actions like moving an object in the 3D world. Information about procedures and items is displayed in the text area below the environment view window (see Figure 5). The environment also allows the learners to switch between different types of movements within the 3D world such as walk, pan or jump.
CSU virtual chemistry laboratory is still under construction and current development work focuses on allowing the learners to undertake virtual experiments and to zoom into the molecular level.

Figure 5 The CSU Virtual Chemistry Laboratory

The next section presents the theoretical framework of this thesis.

4 Theoretical Framework

In this section a brief overview of learning theories: behaviourism, cognitivism and constructivism; and the process of instruction is presented.

There are many approaches to learning that have been discussed and debated by psychologist and instructors over the century; a full discussion of all existing learning theories or approaches is beyond the scope of this thesis. The following points will be discussed:

- Learning theories
- The process of instruction

4.1 Learning Theories

There are three basic approaches underlying the nature of learning, which are, behaviourism, cognitivism and constructivism and each will be discussed in relation to the following themes:

- The nature of knowing
- The nature of learning and transfer
- The nature of motivation and engagement

4.1.1 Behaviourism

Behaviourism approaches in learning can be said to have begun in the 20th century, primarily with the work of Edward Thorndike followed by B.F Skinner. Thorndike conducted research known as operant conditioning, which means, the use of rewards and punishments to modify behaviour. B.F.Skinner followed the work of Thorndike and extended it by demonstrating basic behavioural rules such as positive reinforcement or reward, negative reinforcement, and punishment. Broadly speaking, behaviourism maintained that the psychology of learning should restrict itself to the study of observable behaviours and environmental events.

The nature of knowing in a behaviourist perspective is viewed as an organized accumulation of associations and components of skills. In other words, knowing is viewed as having an organized collection of connections among elementary metal or behavioural units. The behaviourist view on knowing emphasises that what someone knows is often a reflection of that person's experience, and that coming to know something requires an experience in which that knowledge can be acquired (Greeno *et al*., 1996).
Learning is viewed as the acquisition and strengthening of responses (Wilson and Myers, 2000). In other words, learning is the formation of the associations between ideas or stimuli and responses. A response to one situation comes to be associated with another situation thus making transfer possible.
Motivation and engagement in learning occurs because of rewards, punishments and positive or negative incentives. This means that without reward or punishment there is no motivation for learning.

4.1.2 Cognitivism

Most congnitivist psychologists found the behavioural approach unsatisfying when it came to explaining the processes inside the human mind. Around 1970s cognitive psychology became a more dominant paradigm for learning. Cognitivism emphasises the process that goes on in the mind of individuals, such as memory, motivation and others unobservable internal processes. Wertheimer, the founder of Gestalt psychology, contributed much to the development of cognitivism and the idea that people learn through insight.

Cognitivism views knowledge as symbolic, mental constructions in the minds of individuals. In other words, information and processes are organised as constructed patterns of symbols.
Learning is viewed as acquisition or reorganization of cognitive structures through which individuals process and store information.
Transfer of knowledge depends on acquiring an abstract mental representation that can be transferred to other situations.
Motivation and engagement comes from the person's interest in learning and engaging in activities, it is a relation between individual and the organisation of information. There are three elements that help motivation: challenge, fantasy and curiosity (Greeno *et al*., 1996).

4.1.3 Constructivism

Constructivism has lately emerged as a challenging learning paradigm to cognitivism. There are different approaches to constructivism that are cognitively and socially oriented. Piaget and Vygotsky, among other theorists can be described as constructivists.
Vygotsky's theoretical framework is based on the idea that every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (inter-psychological) and then inside the child (intra-psychological) (Vygotsky, 1978).

The main idea behind constructivist perspective is based on the individual's own knowledge construction and understanding of the world through experiences. Another important aspect of constructivist is based on the theory that learning always occurs in some context, and that the context affects learning. This is also known as situated learning.

The constructivists view knowledge as a constructed entity made by each learner through a learning process. Piaget states that: "*Knowledge is actively constructed by the learner, not passively received from the environment*" (Piaget, 1976). When it comes to transfer, knowledge cannot be transmitted from one person to the other, but is constructed by the individual.
Learning is viewed as the process of discovering and transforming complex knowledge structures and adjusting mental models to derive meaning.
Motivation and engagement is an autonomous process where the individual gains ownership of the learning activity, thus engaging in discovering and experiencing real-world activities.

4.2 The Process of Instruction

Having discussed the different perspectives of learning, it is necessary to discuss the process of instruction and the stages that should be present when designing new instructions. The term instruction should be understood as the creation and use of environments in which learning is facilitated (Alessi and Trollip, 2001)
Alessi and Trollip (2001) suggest four activities that should be present in an instruction in order to facilitate learning in an effective and efficient way:

- Presenting information
- Guiding the learner
- Practicing
- Assessing learning

Presenting Information
Information can be presented in a number of ways; for instance, it can be presented verbally or pictorially, or by showing videos or animations, or audiently by listening to a tape. The presentation of information can be accomplished by any medium. An important method of presenting information is through examples, since most learners require more than one example before they are able to apply a rule or skill.

Guiding the Learner
The process of guiding the learner is interactive because it includes the learner and the medium. Alessi and Trollip point out that guidance is important in instruction because learners make errors and are frequently unaware of it. Learners must be made aware of the errors they do in order to correct them.

Practice
Skills should be practiced more than once in order to achieve retention; practice should be repetitive. Individuals need to retain information permanently and not for a short time. When it comes to practice, it is the learner's emphasis on practicing a new acquired skill that makes retention possible. Practice is learner centred, even though an instructor or interactive medium may observe the learner and makes correction when errors are observed.

Assessing Learning
Instruction is often considered to be the presentation of information, guiding the learner and practicing the new acquired skills. However, instruction should also include assessment; learning should also be assessed with tests; which are important part of the instructional process. Assessing learning provides information about the quality of teaching, the level of learning and future instructional needs.

Having discussed some of the most important basic learning theories and what the process of learning may involve; the next section discusses the methods and the models for designing and implementing multimedia programs. The focus of the next section is on the methodology chosen for designing and developing the 3D prototype.

5 Methodology

In this section a discussion of the methods and models that can be used to design and develop multimedia-learning programs are presented, followed by a discussion of the chosen method to be applied in the design and development of the 3D prototype.
For the planning, design and development of the 3D prototype the theoretical basis and methods suggested by Alessi and Trollip (2001), Donald A. Norman (1988) and Alan Dix et al. (1997) for designing and developing programs will be discussed in this section.

The four components discussed under section 4.2: presentation of information, guiding the learner, practice and assessment can also be applied when designing multimedia programs. There are several goals for developing a multimedia program. A computer program can be used to present initial information with further guidance from the instructor; it can be used to review material that initially had been presented in a lecture. A computer program can also be used for the first three phases, where assessment will be done in the traditional way. If a computer program should be responsible for total instruction the four components described under section 4.2 should be present.

Alessi and Trollip (2001) suggest eight methodologies for designing and developing interactive multimedia programs, these are: tutorials, hypermedia, drills, simulations, games, tools and open-ended learning environments, tests and web-based learning. A discussion of these eight methodologies is beyond the scope of this thesis.
From these eight methodologies, web-based learning was chosen as the methodology basis to be used for the design and development of the 3D prototype.

5.1 Web-based Learning

Web-based learning is a method for developing a learning environment when using the web as a delivery system; it is possible to combine various technologies, such as visual, audient, and text. Web-based learning is designed using hypermedia methodology. Hypermedia is based on hypertext, which means, text that contains pointers to other texts that are related. The term hypertext has its origin in the work of Vannevar Bush and Theodor Nelson. Bush and Nelson proposed a new way of designing and storing information that would be easier to manage and use by linking texts that are related. Hypermedia consists not only of hypertext, with information linked together, but also includes objects like images, audio and video.

The web is used for learning in mainly two ways: 1. traditional on-site learning and
2. support for distance learning.

- **On-site Learning**: Is learning in the traditional way, where people attend to a classroom where learning and instruction take place
- **Distance Learning**: Is learning that take place in different locations, this means that the learners use a program on the Web to get instructed

There is no general agreement on how to design web sites for learning; this is due to the Web’s nature where anyone can publish a web site with or without guidelines. However, there are some guidelines that suggest standards to be used when developing web sites, for instance, the guidelines proposed by W3.org [4].

The most common methodology for web-based learning is hypermedia. There are several factors that can be taken into account when developing web-based learning instructions. The following factors apply both to hypermedia and web-based learning: navigation, orientation, hypermedia format, browsers, speed, multimedia components, visual layout, interactivity and user controls. These factors will be discussed briefly in the following sections.

5.1.1 **Navigation**

Navigation refers to the ability to get to the intended destination. The navigation used in web-based learning programs is the same navigation method used in hypermedia. These navigation methods are: hyperlinks, buttons, menus, indexes, tables of contents, maps, pictures, and text searching, among others. These navigation methods will be thoroughly discussed under section 7.4.1. Table 1 shows some examples of what is meant by navigation methods.

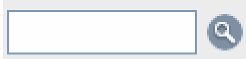
Navigation method	**Example**
Hyperlinks: Take the user to a destination inside or outside the same site	This is a hyperlink
Buttons: May allow navigation back or forward between pages	
Menus: Give a list of choices allowing direct navigation between web pages or site locations	
Text searching: Allows users to find text or pages quickly	

Table 1 Navigation methods, examples

5.1.2 **Orientation**

The concept of orientation means knowing where you are. Visualizing where you are in the program is very important to avoid getting lost in hyperspace. Because of the nature of the Web, where every web site has different layouts and navigation methods, it has become more difficult to keep the user oriented of where they are in hyperspace. There are some orientation cues like navigation metaphors, frames, sitemaps, bookmarks, among others, that help users to keep oriented in a web-based application. Orientation methods will be discussed under section 7.4.2. Table 2 shows some examples of orientation methods.

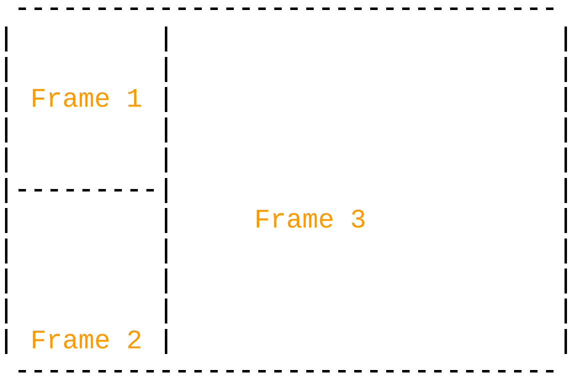
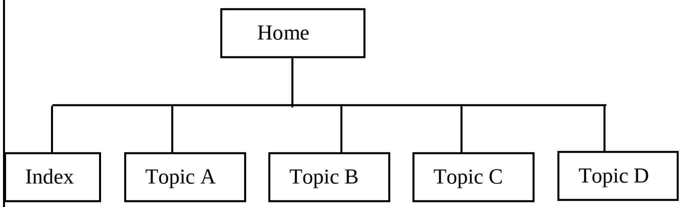
<table>
<tr><th>Orientation method</th><th>Example</th></tr>
<tr><td>Frames: Allow dividing the screen in different sections so information can be displayed in one section while keeping another part of the window unchanged</td><td>
</td></tr>
<tr><td>Site maps: Give a pictorial overview of the program, allowing the user to know the current location in the site</td><td>
</td></tr>
<tr><td>Bookmarks: Allow users to mark pages or sites locations, thus making navigation easier</td><td>
</td></tr>
</table>

Table 2 Orientation methods, examples

5.1.3 Browsers

When designing and developing a web-based learning instruction, one must think of browser compatibility. There are different browsers on the Web, each one supporting different features and functions. Unfortunately there is no standard between the browsers and it is very difficult to make a web site that is compatible for all browsers. For instance MS Internet Explorer supports a variety of 3D plug-ins that are not supported by Netscape, Mozilla or Opera. On the other hand, Mozilla and Opera browsers support more advanced programming features that are not supported by Internet Explorer or Netscape. Frames may also be a problem when being displayed in other browsers rather than Internet Explorer or Netscape.

5.1.4 Speed

A web-based learning instruction depends not only on browsers, but also on network communication. The bandwidth in which the target user's computers are connected is crucial when choosing the type of file formats that the program can display.

5.1.5 Multimedia Components

There are different multimedia components to choose from that can be included in a web-based instruction, for instance, movies, sounds, animations, text, images, among many others. The choice of multimedia format depends on the network speed of the computers in which the instruction is to be used.

5.1.6 Visual Layout

Alessi and Trollip (2001) give a number of recommendations when it comes to the visual layout of a program. They point out that web-based programs make more use of multiple windows than most other applications. It is also a common feature of the Web for links to audio, video or animation to appear in their own windows. It is recommended to use a small number of windows; to make clear to users if a link will open a new window.

Most web applications use scrolling. A common observation when using the Web is that users do not scroll and fail to read information that is placed at the bottom of a page. It is recommended avoid putting directions, interactions or critical information in positions that require scrolling.

Another recommendation is to use frames, which allow splitting the window in different areas. The areas may be used for different purposes for instance; one frame may remain constant while another frame displays instructional information.

Tables can also be considered to improve visual layout. Tables permit precise formatting of the displayed information. Figure 6 shows an example of a web application with frames and scrollbars.

Figure 6 A web page with frame and scrollbars

5.1.7 Interactivity

The Web is primarily used as an electronic book for hypertext, with little interactivity. Most sites present text, sound and movies, but lack other types of interaction like quiz, controlling or manipulating objects, making choices, or program response to user actions. The Web is not designed for rapid interaction due to the underlying language hypertext markup language (HTML) that does not include many functions that permit user interaction. However, the Web can support much higher levels of interaction; for instance, it is possible to support quiz or self tests by using JavaScript language. It is also possible to include three-dimensional interaction with objects or virtual worlds. VRML is an extension of HTML that allows the creation and displaying of 3D objects on the Web.

There are also more advanced forms for interactivity on the Web, for instance, embedding 3D virtual worlds into web sites, although this feature is relatively new and all browsers do not support it. Figure 7 shows how the web can become more interactive by adding 3D VRML model to a web page thus creating more real-time effects.

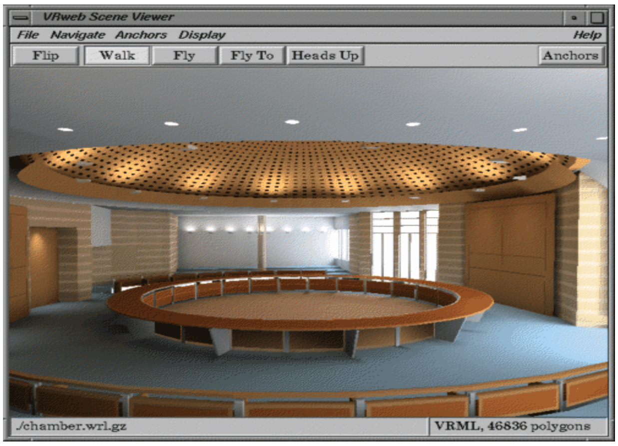


Figure 7 **Virtual world**

5.1.8 User Controls

The Web provides the user with the possibility to control a program more freely. It is important to provide controls that are easy to use. Web-based instructions should provide the users with the possibility to turn on or off controls. There are many types of user controls, for instance, users should be able to forward, rewind, pause and exit a program; searching or access to help; access to printing or copying. When using video, audio or animations, users should be able to pause, continue or repeat a sequence. Figure 8 shows an example of user controls for playing an animation in a web page.

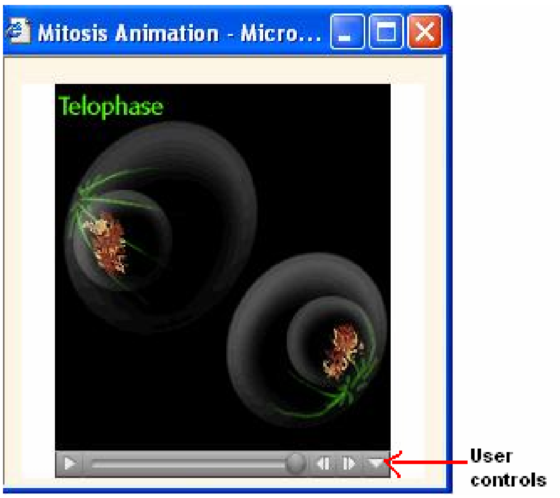


Figure 8 **User controls, playing a Quick-time animation**

The next section presents first a general discussion of some design and development models use for developing programs, followed by a detailed discussion of the chosen model that will be followed for the design and development of the 3D prototype.

5.2 Design and Development Models

There are several models that address the management and technical issues of design and development of software systems. In this section, two models will be presented; one is the waterfall model of software life cycle used in user-centred design as described by Alan Dix et al. (1997). The other is a model for design and development of multimedia-learning programs suggested by Alessi and Trollip (2001).

The waterfall model is used for software life cycle, which describes the activities that take place from the initial concept of a program to its eventual phasing out and replacement. The activities in the waterfall model are divided into several steps. The steps are sequential and each activity leads into the next. Sometimes it can be necessary to return to a previous step to make changes before going on to the next step. Such models are more iterative.

Alessi and Trollip's (2001) model (Figure 10) is very detailed and it focuses on design of multimedia learning programs. However their model is not very different from other models, for example, the waterfall model (Figure 9). Alessi and Trollip's (2001) model, as in the waterfall model, is divided into three sequential steps. Each step is iterative, meaning that one can go back to a previous step or phase if necessary. This iterativity is described as ongoing evaluation, where designers can go back to an early stage of design in order to correct errors. The waterfall model and Alessi and Trollip's (2001) model will be discussed in the following sections.

5.2.1 The Waterfall Model

According to Alan Dix et al. (1997) the software life cycle is an attempt to identify the activities, which occur in software development. In the development of a software product, two main parties are considered; the customer who requires the use of the product and the designer, who must provide the product. These two parties interact with each other during the design and development of a product. The activities in which the customer and the designer take place must be structured according to the steps depicted in Figure 9.

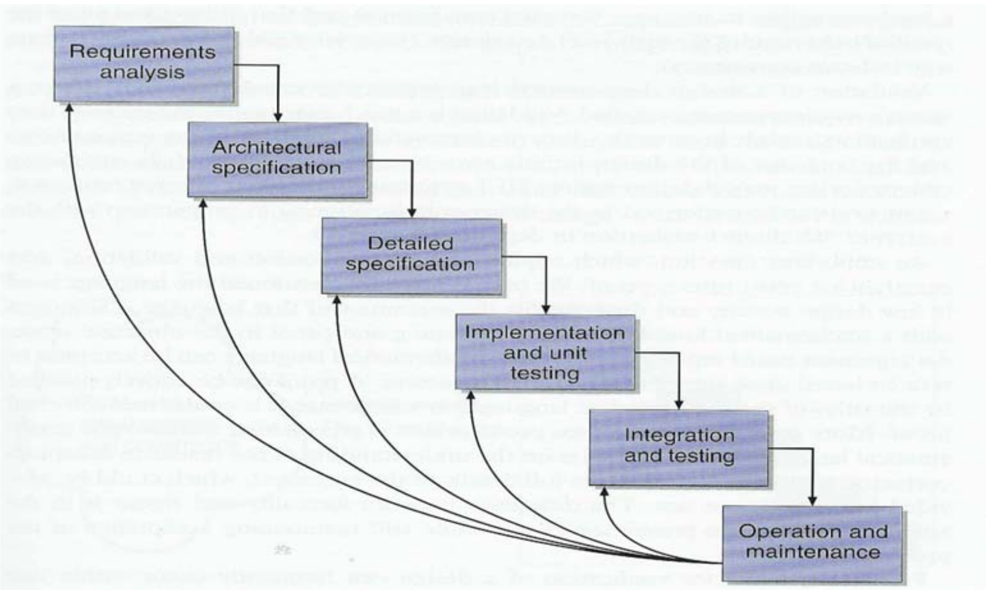


Figure 9 The waterfall model with feedback from maintenance activity to other activities

The model depicted in Figure 9 was taken from Dix et al. (1997). It starts with the step of *requirements analysis*; during this step, a description of what the eventual system will be expected to provide is collected.
The next step is *architectural specification* that concentrates on how the system provides the services expected from it, in other words, the system is deconstructed in components in order to determine whether each component needs to be developed from scratch or some already existing components can be used and adapted to the new system.
Detailed specification provides an overview of the system and a description of the components that should be developed and a detailed description of how each component should be implemented. The next step, *implementation and unit testing,* includes the coding of the components in the appropriate programming language, this steps includes testing of the program to see if it works properly.
Integration and testing step consists on integrating all the components into the system and test the system with the users in order to discover design errors early. The final step, *operation and maintenance* involves the correction of errors (bugs) in the system, which are discovered after release. This step is iterative, its provides feedback to all of the other steps as shown in Figure 9.

The waterfall model of software system life cycle is used in user-centred design. According to Donald A. Norman (1988) User-centred design is a "philosophy based on the needs and interest of the user, with an emphasis on making products usable and understandable"(Donald A. Norman, 1988).

Donald Norman (1988) suggests taking into account the following point during design phase:

- Make it easy to determine what actions are possible at any moments

- Make things visible, including the conceptual model of the system, the alternative actions, and the result of actions

- Make it easy to evaluate the current state of the system

- Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state

He suggests that a designer has to make sure that the user can figure out what to do and the user can tell what is going on in the system.

> "Design should make use of the natural relationships and natural constraints: As much as possible, it should operate without instructions or labels. Any necessary instruction or training should be needed only once"… "A simple explanation will suffice if there is reason to the design, if everything has its place and its function, and if the outcomes of actions are visible" (Donald Norman, 1988).

5.2.2 Model for Design and Development of Multimedia Learning Programs

The following section describes the model to be followed under planning, design and development phases for the 3D prototype. The reason for choosing this model is because it is very detailed and explains step-by-step how multimedia-learning programs should be designed and developed; which is very helpful for inexperienced system developers. Moreover, the 3D prototype to be developed is intended to be a web-based learning program, which falls into the category of multimedia-learning programs described by Alessi and Trollip (2001).

Alessi and Trollip (2001) propose a model to be used as guidance in the planning, design and development phases of multimedia programs. The model described in Figure 10, has three phases, which are, planning, design and development. The model also includes three attributes which are standards, ongoing evaluation and project management. This model was designed to be flexible, so each developer can adjust it according to their project's needs.

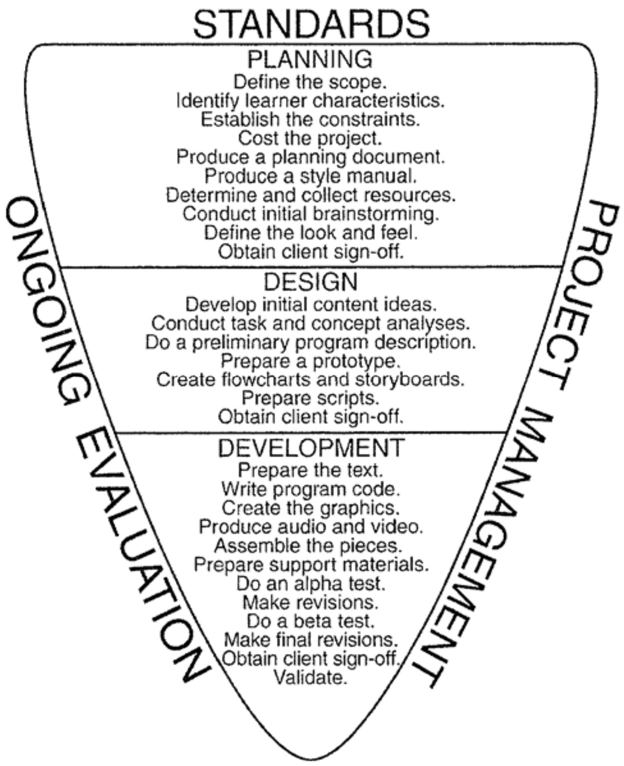


Figure 10 Model for design and development

Standards

Standards may include details of how the program will look, for instance, fonts, colours, the overall look and feel, and the level of detail of the content and any other guideline available for the intended system.

Ongoing Evaluation

An ongoing evaluation will ensure quality of the system and that standards are being followed during design and development phases. Making evaluations help to discover and correct errors at early stages of design and development phases. This means going back to an early stage of design and this will again result in an iterative process of design.

Project Management
This attribute includes good management of resources and time. All elements of the project must be under control. It is important to have a good planning and to monitor the progress of the projects activities against the plan.

Planning
The first phase in developing interactive multimedia products is planning. This phase will give a general understanding of what the project is about. During the planning phase, the project goals are established, including the learner's knowledge, which can be determined by identifying learner characteristics. Another important point during this phase is it to determine the constraint when it comes to software and hardware in which the program will run. Planning should also include collecting resources; this may include collecting textbooks, multimedia programs available or other resources needed for the design and development of the program. Initial brainstorming should also be carried out with users, in order to establish the content and the general look and feel of the program.

Design
The design phase is probably the most important, since it is during this phase that all the details for producing an effective product are described. During this phase initial content ideas are developed, brainstorming can be carried out with users to come up with so many ideas as possible about the content. Further, a task analysis should be carried out. The purpose of task analysis is to decompose complex skills into sub skills; in this way one can determine the appropriate learning sequence. Another step during design phase is to do a preliminary program description, which may include describing in detail the type of methodology used for implementing the program. Prototypes are an important part of the design, because prototypes can describe to some extent how the program may look and work.
During this phase, flowcharts and storyboards are also created to show the general or detailed flow of the program.

Development
This phase is when all the planning and design steps are activated to produce the program. During this phase all the computer code is written to make the whole program function. All the material that the program may include such as images, animations, videos, movies, audio, text, and controls should be produced and assembled together. The support materials such as user guide or manual should be produced. It is very important to do alpha testing during the development phase. An alpha test should be carried out by experts and will discover design problems early, before the program is ready. Each test should be followed by revision in order to make the necessary changes in the program and eliminate problems. Beta testing should be carried out with a larger group of users. A final revision after performing a beta testing should be done in order to correct usability and design problems of the program before it is ready for deployment.

After discussing the chosen methodology for developing multimedia programs; which is: web-based learning and the chosen model for designing and developing multimedia programs (see Figure 10), it is appropriate to present in the next section all the steps that were applied under planning, design and developing phases of the 3D prototype.

6 Planning the Design of the 3D Prototype

In this section the steps used for planning the design of the 3D prototype will be presented. A schedule of the activities as well as the persons involved during this phase is presented first in Table 3.

Meeting date	Person involved	Activity
22.08.2003	Helga Sunde, middle school teacher at Ytrebygda school, Hjellestad, Bergen, Norway	Meeting at Ytrebygda middle school. A preliminary discussion about the topics to be included in the 3D prototype took place. The teacher also provided text books and the curriculum plan for the 10th grade
05.09.2003	Helga Sunde, secondary school teacher, at Ytrebygda school, Hjellestad, Bergen, Norway	Meeting at Ytrebygda middle school to discuss the learner's characteristics and choose the students that will be involved during design, and evaluation phase of the 3D prototype, as well as to establish some deadlines for the activities involving the students
24.09.2003	Two 10th graders students and the network assistant at Ytrebygda school, Hjellestad, Bergen, Norway	Meeting at Ytrebygda middle school with the two chosen students. The purpose of the meeting was to explain to the students what this thesis is about, as well as to clarify and show examples of what 3D learning environments are and what is expected of them during design phase of the 3D prototype. At the end the students were interviewed and asked questions about their familiarity and ability with computers. After meeting the students. The software and hardware available at Ytrebygda school was classified by the network assistant and noted down

Table 3 Planning phase schedule

For the planning of the 3D prototype some of the steps in the model depicted in (Figure 10) were followed. The planning phase gives a general understanding of what the project is about. The following steps of the planning phase will be discussed:

- Define the scope of the content
- Identify learner characteristics
- Establish the constraints
- Determine and collect resources
- Define the look and feel

6.1 The Scope of the Content

During this step it is necessary to establish what is to be learned and by whom. In order to establish the scope of the content a meeting with the teacher of the class took place on 22.08.2003 (see Table 3 for details). During this meeting, several topics of the natural science curriculum that include abstract concepts were discussed with the teacher, Helga Sunde. The discussion was based on several textbooks including the textbook used by her class: (Tellus10, Natur-og miljøfag for ungdomssteget, 1999) and the curriculum plan for 10th graders (Læreplanverket for den 10-årige grunnskolen, 1996). The following chapters of

Tellus10 textbook were reviewed: Chapter 3: Carbon chemistry, chapter 4: Diet and digestion and chapter, 7: Genes and inheritance. After reviewing and discussing the textbook, the teacher came up with the following topic to choose from:

- Carbon chemistry
- Genes and inheritance
- Diet and digestion

The topics suggested are those that have most abstract concepts. Scientific abstract concepts may be more difficulty to understand and grasp by middle graders students.

Including all the above topics is beyond the scope of this thesis. After discussing this matter with the teacher, it was decided to implement only one module, carbon chemistry, since this module was considered to be the most abstract for the students.

6.2 Identify Learners Characteristics

6.2.1 The Subjects and Their Level of Competence

In order to establish the learner characteristics of the target users, a meeting took place on 05.09.2003 (see Table 3) at Ytrebygda School with the teacher, Helga Sunde. It was important to identify the level of competence of the target users, since this varies from learner to learner. The target users were 10^{th} graders from Ytrebygda middle school. According to the teacher, Helga Sunde, they all had the preliminary skills and knowledge needed to learn the new topics that would be included in the 3D prototype. During this meting, the teacher divided the level of competence by three different skills and knowledge levels: weak, average and strong learners. 2 students out of 24 would participate during the planning and design phase of the 3D prototype. The remaining 22 students would use the 3D prototype when it was ready for deployment.

In order to choose the 2 students who would participate in design and evaluation phase, the following criteria were discussed during the meeting:

- Student's knowledge about the chosen topic
- Student's ability (quick, average or slow) with instructions
- Student's learning interest and motivation
- Student's personality (level of confidence)

After taking into account the four criteria listed above, the teacher selected two students, one male and one female. They were both strong learners and had the preliminary level of competence. They both had a high level of confidence and were very engaged and motivated to participate in this project. Table 4 and Table 5 show the learner characteristics chart of these two students.
These charts were partly completed by the teacher and partly by the students themselves, after interviewing them on 24.09.2003 and asking them questions about their ability with computers. The teacher, Helga Sunde, provided the part about reading level, motivation, prerequisite knowledge and skills. The students provided the rest of the information.

Learner characteristic chart: Learner #1			
Item	**Weaker learners**	**Average learners**	**Stronger learners**
Age			15, female
Educational level			10th grade
Reading level			Average
Motivation			Medium
Prerequisite knowledge			Basic natural science
Prerequisite skills			Above average
Facility with a computer			Average
Familiarity with the Web			Reasonable
Typing ability			Medium
Access to computers			Both at home and at school
Access to web			Only at school
Time available			10 hrs

Table 4 Chart of learner characteristics, learner #1

Learner characteristic chart: Learner #2			
Item	**Weaker learners**	**Average learners**	**Stronger learners**
Age			15, male
Educational level			10th grade
Reading level			Above average
Motivation			High
Prerequisite knowledge			Basic natural science
Prerequisite skills			High
Facility with a computer			Above average
Familiarity with the Web			High
Typing ability			Medium
Access to computers			Good
Access to web			Both at home and at school
Time available			10 hrs

Table 5 Chart of learner characteristics, learner #2

6.3 The Constraints

For web-based learning programs it is important to know the hardware and software constraints of the systems in which the program will run. The reason why this is necessary is because many web-based learning programs need powerful processors to run effectively. List 1 shows the system requirements necessary to run the 3D prototype:

- Intel Pentium II or faster processor
- Microsoft Windows 2000, Windows NT4.0
- Microsoft Internet Explorer 5.0 or higher
- Adobe Atmosphere player 195 plug-in or higher
- Cortona VRML Client 4.1
- Quick time player 5.0 or higher
- 128mb RAM
- 14 MB of available hard-disk space
- 16-bit colour or (32-bit colour)
- 56K modem or faster Internet connection

List 1. System requirements

An important feature of web-based learning programs is that it should be compatible with all types of browsers. The 3D prototype has the constraint that it will only run in Microsoft

Internet Explorer 5.0 or higher. The reason for this is that Adobe Atmosphere player plug-in necessary to visualize and use the 3D scene, is only supported by Microsoft Internet Explorer 5.0 or higher versions.

The hardware and software constraints of Ytrebygda middle school were established the 24.09.2003 (see Appendix A: Table 1 and 2). The network assistant helped to complete the necessary information.

6.3.1 Timelines

Timelines were established as a guideline for the work to be done under design and development phases (Table 6). During the meeting on 05.09.2003 (see Table 3 for details), certain deadlines were suggested by the teacher. The reason for setting these deadlines was to ensure that the students would be able to both complete their duties to the current project as well as other obligations not related to this project.

Constraint: Timelines		
Deadline	**Activity**	**Persons involved**
Starts: 15.09.03 Deadline: 30.11.03	Planning and Design	The teacher, two students and the system designer (author)
Starts: 30.11.03 Deadline: 30.01.04	Development	The system designer (author)
Starts: 01.01.04 Deadline: 30.01.04	Formative evaluation: Expert review	The Teacher, Helga Sunde and the evaluator (author)
Starts: 01.02.04 Deadline: 30.02.04	Formative evaluation: one-on-one evaluation	Two students
Starts: 01.03.04 Deadline: 30.03.04	Formative evaluation: one-on-one evaluation	Four middle school teachers: Anne Aasdal, Kirsten Knudtzon, Idar Mestad and Brit Aarstad and the evaluator (author)

Table 6 Timelines constraints

6.4 Resources

During the planning process it was important to gather, as much resource materials as possible. The collected materials and resources included any type of item that could aid in the development of the instructional 3D prototype.

The resource materials that were used during design and development phases were:

Subject Matter Resources: This type of resource included any item that contained information about the subject to be learned, such as textbooks, training materials, other multimedia programs, and reference materials. Table 7 shows a list of the subject matter resources collected.

Resources and Tools		Description
Books	Tellus 10 (natur og miljøfag for ungdomssteget)	Provided by Ytrebygda school. This is the textbook used by the school
	Helix 10 Natur-og miljøfag for 10.klasse.	An alternative textbook for teaching of natural science
	Læreplanverket for den 10-årige grunnskolen, 1996	Provided by Ytrebygda school
Multimedia programs	Microsoft Encarta 2000 Encyclopaedia	CD-room
	MOLECULES: Molecular modelling for chemical education	A web-based tutorial by the Lebanon Valley College Available at: http://www.molecules.org/
Computer tools	VRML File Creator for Chemical Structures	This VRML file creator was used to convert PDB files to VRML formats. The VRML File Creator for Chemical Structures is an online service for the generation of VRML scenes from 2D or 3D data files. It supports over 40 structure file formats and contains also a molecule editor for structure input. It automatically generates 3D coordinates if not contained in the input structure. It converts PDB files into VRML formats. The VRML converter is available at: http://www2.ccc.uni-erlangen.de/services/vrmlcreator/index.html
	Chemistry Molecular Models (PDB-database)	The PDB database was used to find molecular structures Available at http://www.uwsp.edu/chemistry/pdbs/
	Protein Data Bank PDB	The PDB database is the single worldwide repository for the processing and distribution of 3D biological macromolecular structure data. Available at: http://www.rcsb.org/pdb/
	Thermoplastic	A web page with useful information about polymers. Available at: http://www.psrc.usm.edu/macrog/plastic.htm
	Library of 3D Molecular Structures	A web-site used to find some molecular structures Available at: http://www.nyu.edu/pages/mathmol/library/
	Molecular Model Library	Web-site used to find molecular structures Available at: http://fp.academic.venturacollege.edu/doliver/pdb_files/molecules/molecule_library.htm

Table 7 The resources

6.5 Look and Feel (Screen Layout)

In order to provide a general idea of how the 3D prototype would appear, some sketches or mock-ups of the computer screen were drawn on paper during a meeting on 24.09.2003 at Ytrebygda middle school. During this meeting the present study was explained to the two selected students mentioned in section (6.2.1). The students also saw some similar applications of 3D learning environments available on the Web, for instance, those developed by Atmosphere Educational Environments [5].

The two learners were shown a mock-up of the computer screen. The intention behind this mock-up was to make them start thinking about how they would like the 3D prototype to look. Since these two students were quite young and did not have any experience with prototyping or drawing screens layouts. This example was absolutely necessary for them, in order to come up with ideas during design phase.

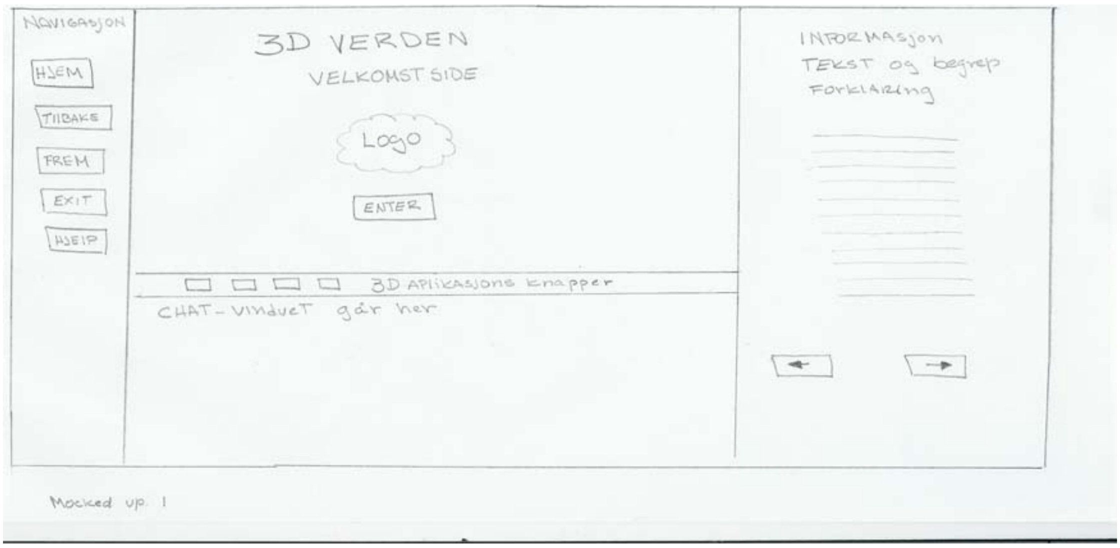


Figure 11 **Example of a mock-up**

This section presented the steps that took place under the planning phase of the 3D prototype. Under this section the following steps were described: the scope of the content to be implemented in the 3D prototype; the characteristics of the learners that implies what is the level of competence of the target users; the software, hardware and timelines constraints; the resources and materials available for implementation; and the look of the program which implies the screen layout of the 3D prototype.

The next section presents the steps that took place under design phase of the 3D prototype.

7 Designing the 3D Prototype

During the design phase two meetings took place at Ytrebygda middle school.
Table 8 summarizes the time, place, persons involved and the activities that took place during design phase of the 3D prototype.

Meeting date	Persons involved	Activity
21.10.2003	Helga Sunde, teacher at Ytrebygda school, Bergen, Norway	Discussion about the topics to be included in the 3D prototype, brainstorming session.
10.11.2003	Two 10^{th} graders students at Ytrebygda school, Bergen, Norway	Prototyping, drawing mock-ups of the screen layout

Table 8 **Schedule for design phase**

During the design phase all the details for producing an effective product were described. The model depicted in Figure 10 suggests a number of steps for this phase. The following steps were taken into account during design phase of the 3D prototype:

- Initial content ideas
- Task analysis
- Prototyping
- Methodology (preliminary program description)
- Create flowcharts

7.1 Initial Content Ideas

The objective with this step was to develop initial and specific ideas about the content of the 3D prototype and how the content could be learned. Alessi and Trollip (2001) suggest using brainstorming for this purpose. Therefore, a brainstorming session was conducted with the teacher, Helga Sunde, as the content expert, during a meeting on 21.10.2003.

7.1.1 Brainstorming

The list presented in Table 9, is the final list of all the ideas that came up during the meeting with the teacher and only includes the ideas that would be implemented in the 3D prototype. Two textbooks were used (Tellus 10, natur og miljøfag for ungdomssteget, 1999) and (Helix 10, Natur-og miljøfag for 10.klasse, 1999) to come up with ideas about which subtopics of carbon chemistry should be included.
After discussing with the teacher, the following subtopics of carbon chemistry were suggested:

- Molecular representation
- Hydrocarbons
- Polymers
- Hydroxyl groups
- Organic solvents

After deciding which subtopics of carbon chemistry would be included in the 3D prototype, a brainstorming session took place. This session lasted one hour and resulted in the generation of ideas about what content should be included and how information should be presented. The alternatives discussed varied from just explaining concepts by plain text or hypertext, to making images and tables of content to illustrate important categories; making images and video streaming to show some examples of atoms and molecules; including VRML programming to show molecules in 3D format, among other alternatives for presenting information.

List of contents	
Content	**How to learn it**
Topic: Carbon chemistry	
How is a carbon atom composed?	Show a movie model of the carbon atom
Where can carbon atoms be found?	Make a division of the subtopics
How can molecules be represented?	Show a table that illustrates different representations
What are the differences between the types of molecular representations: Molecular formula, wire frame, ball and stick, capped-sticks and CPK or space filled	Show the same 3D model in different representations to illustrate the differences between the models. Make a table of contents with images
What are the properties of carbon atoms?	Show a figure of a carbon atom and explain its properties Show a movie
What are single, double and triple atomic bonds?	Make a table, with images to illustrate the differences
What is plastic?	Explain the concept with examples, images and show 3D models of different kind of plastics
Where are plastics found?	Give practical examples of what kind of objects are made of plastic
What do alcohol molecules look like?	Show a 3D model
What types of alcohols molecules are there?	Make a table with images and examples, and show also 3D models
What are organic solvents?	Explain the concept and show images, make a table with images of it
What can organic solvents do?	Give practical examples of organic solvents

Table 9 Brainstorming

7.2 **Task Analysis**

The purpose of task analysis was to decompose complex skills into sub-skills; in this way one can determine the appropriate learning sequence. A good learning sequence should begin with skills that only require the learner to use and combine skills they already have. The sequence should proceed from basic to more complex skills. Diagram 1 shows the sequence that would be followed for learning the carbon chemistry topic.

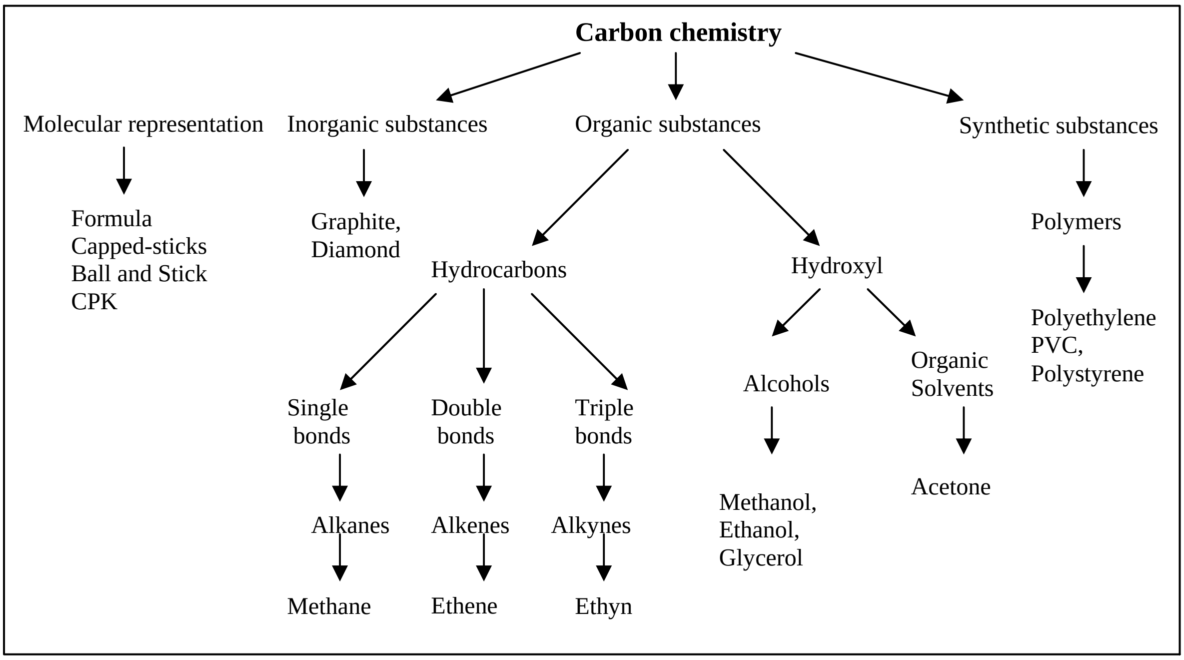


Diagram 1: Sequence of carbon chemistry topic

The topic of carbon chemistry is very wide; however, the 3D prototype would only include the subtopics outlined in (section 7.1.1) in order to remain within the curriculum of 10th grade students.

According to the curriculum for middle schools in Norway, students should master some natural science subjects:

Sub-objectives for the topic of chemistry of the natural science curriculum

- Students shall learn concepts about atoms, molecules, elements, and chemical bonding, and distinguish between different types of molecular model representations, (Læreplanverket for den 10-årige grunnskolen, p. 216, 1996)

- Students shall learn to distinguish between different types of chemical bonding and describe them in general terms (Læreplanverket for den 10-årige grunnskolen, p. 216, 1996)

- Students shall conduct experiments to see how elements react in contact with others and how they make new atomic bonding with new qualities. (Læreplanverket for den 10-årige grunnskolen, p. 216, 1996)

7.3 Prototypes

The primary reason for prototyping is to gather user feedback to an evolving design. A prototype can describe to some extent how the program may look and work. (Vredenburg *et al.*, 2002).

The use of a prototype is important in an iterative development methodology because prototyping provides better collection of user requirements, it is time saving, it increases the quality of the design, it helps to start early testing and it also increases user involvement. Prototypes can be used throughout the design and development phases. There are different types of prototypes:

- **High-fidelity Prototypes**

This type of prototype is fully interactive, meaning that users can interact with the prototype in the same way they would interact with the real application. With high-fidelity prototype users can evaluate navigation, orientation, and other functionalities that the final application will have. A high-fidelity prototype is used during the development phase and is especially used for conducting evaluations of the prototype such as usability, appeal and quality evaluation. High fidelity prototypes were used during the development phase.

- **Low-fidelity Prototypes**

Are used early in the design phase to show the general look of the program and to get the general idea of how the program will operate. It does not include detailed information, but gives a shallow impression of how the program may look. Low-fidelity prototypes are usually drawn on paper and are called mock-ups.

During the design phase some low-fidelity prototypes were produced during the meeting with the two 10^{th} graders students at Ytrebygda middle school on 10.11.2003 (see Table 8). The meeting lasted five hours and took place at the multimedia room of Ytrebygda school. This meting was divided into two sessions.

During the first session (9:00 am to 11:00 am) the students drew two mock-ups to give their ideas about how they wanted the 3D prototype to look, and to some extent, how it should work. They came up with ideas and suggestions of what type of objects and navigation options they would like the 3D prototype to have (see section 7.4.1 and 7.4.2 for details about navigation and orientation techniques).

During the second session (12:00 pm to 2:00 pm) the two students were shown some examples of 3D web-based learning environments on the web. They got some ideas from it and started drawing a mock-up of how the main entry point to the 3D scene should look. The following section gives a detailed explanation of the meeting with the students.

7.3.1 Session 1: Drawing the General Screen Layout of the 3D Prototype

This session took place between 9:00 am and 11:00 am. During this session the students were asked to draw a screen layout of the 3D prototype.

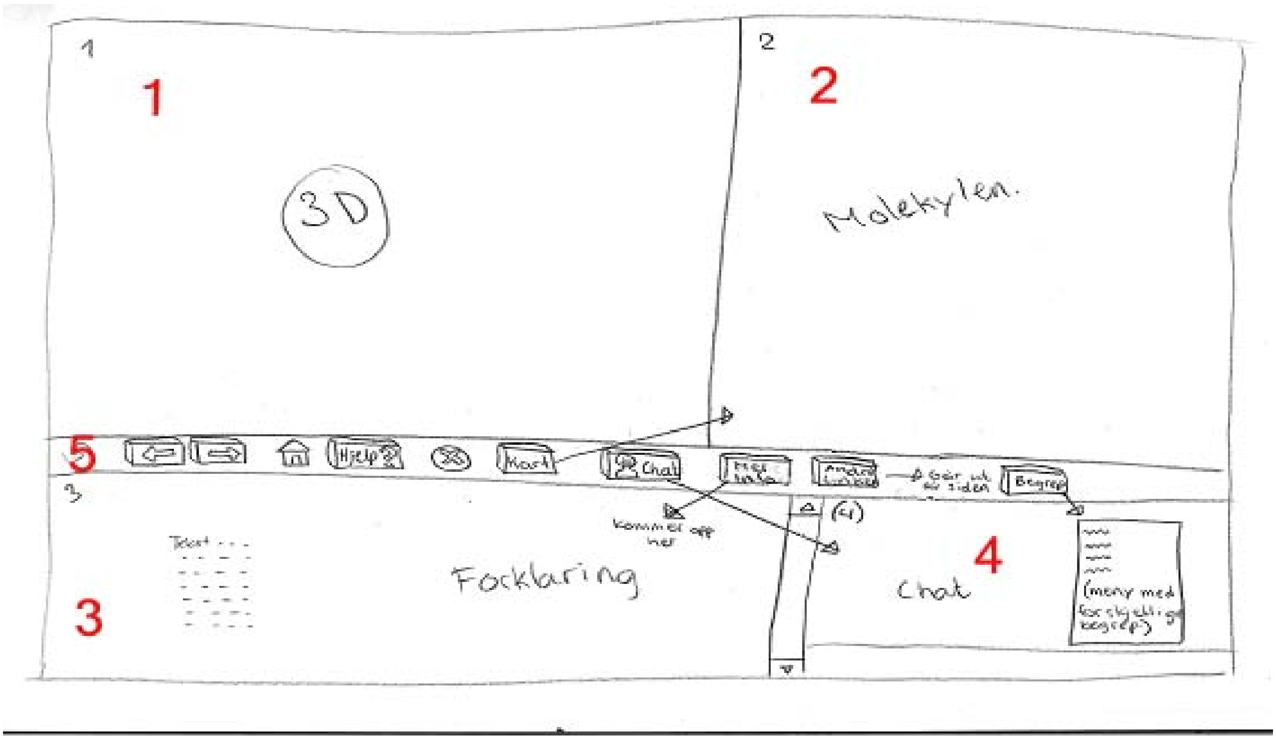


Figure 12 **Mock-up 1. Screen layout of the 3D prototype, Student #1**

The paper prototype (see Figure 12) was drawn by student #1 (see chart of learners characteristics for details about this student under section 6.2.1 Table 4).

This mock-up shows how the screen layout of the 3D prototype was divided into five frames:
Frame (1) shows the 3D scene with avatars (Figure 12: 1).
Frame (2) shows where the molecules would be displayed in the VRML browser (Figure 12: 2).
Frame (3) shows where the text and information should be displayed. (Figure 12: 3)
Frame (4) shows the chat window. This student suggested having the chat window separated from the 3D scene (Figure 12: 4).
Frame (5) shows the navigation buttons and menus that should be displayed in the middle of the screen (Figure 12: 5).

Comments
This student wanted the 3D scene to take the biggest part of the screen, about 50%. This was the reason why the chat window was placed in a separate window.

Use of metaphors: This student wanted to have images and text on the buttons. Look closely at the metaphors suggested in Figure 12: 5.

The following buttons were drawn: (The icons have been redrawn for clarity).

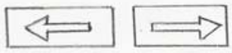
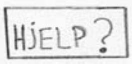
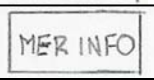
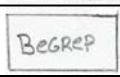
Back and forward buttons using arrows	
A home button for getting back to start position (a house)	
A help button with text and a question mark for help	
An exit button with an X	
A chart button to display the navigation map at frame (2)	
A chat button with a face on it and text, to display the chat window at frame (4)	
An information button with text (more info) to display information in frame (3)	
A button to go to external links (links outside the current site)	
A button displaying important concepts in frame (4). (This may be displayed as a menu of concepts)	

Table 10 **Metaphors, Student #1**

Some of these ideas were taken into account when implementing the 3D prototype.

Session 1, Student #2

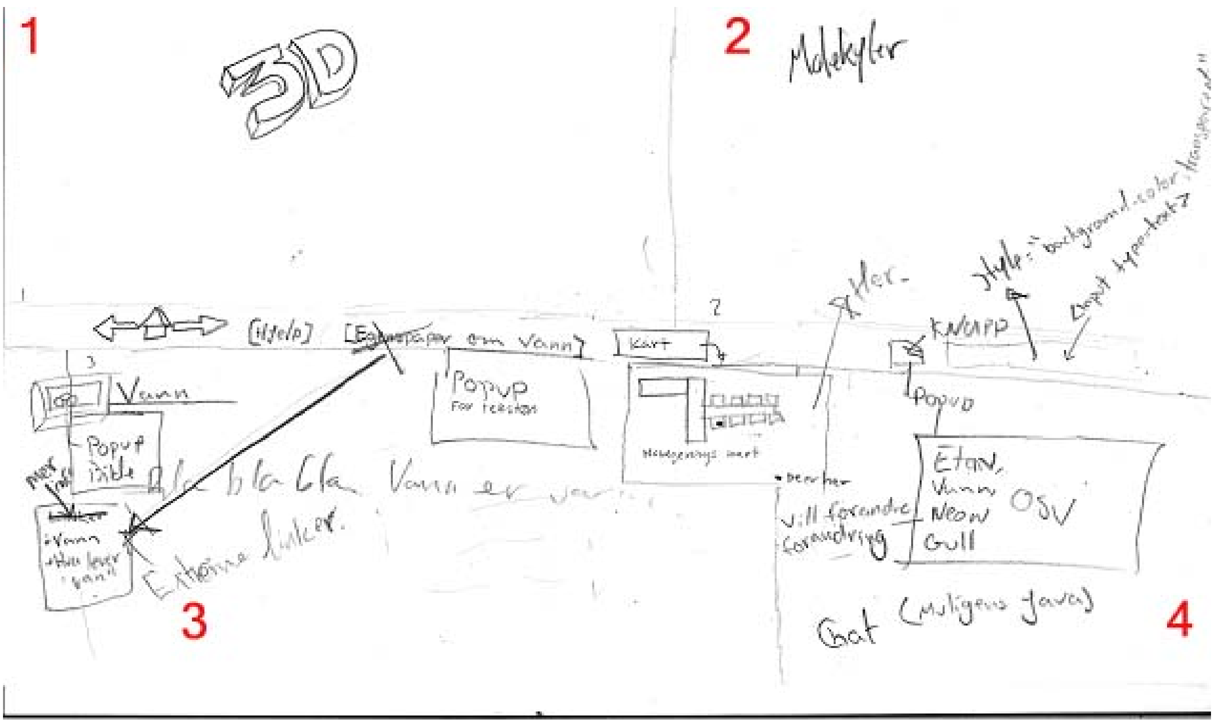


Figure 13 **Mock-up 2. Screen layout of the 3D prototype, Student #2**

Student #2 drew the paper prototype shown in Figure 13. (For details about this student, see the chart of learner characteristics under section 6.2.1, Table 5).

This student divided the screen into four frames.
Frame (1) shows the 3D scene. This student did not specify how big this frame should be (Figure 13: 1).
Frame (2) shows the 3D objects in the VRML browser. This student specified that the VRML browser should not be open at all times, and that this frame could also be used to display any kind of information (Figure 13: 2).
Frame (3) shows the navigation buttons and menus as well as text in tabular form.
This student suggested having pop-up menus to explain difficult concepts (Figure 13: 3).
Frame (4) shows the chat window and information about important concepts (Figure 13: 4).

Comments
Student #2 also suggested that the chat window remain apart from the 3D scene. The chat window can be displayed as a part of the 3D scene or be enabled or disabled. The latter means that students could choose to open or close the chat window at will.

Use of metaphors:
Student #2 suggested the following functions depicted at Table 11. (The icons have been redrawn for clarity).

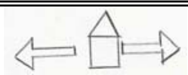
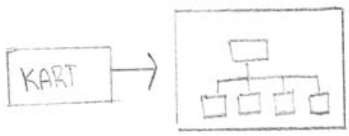
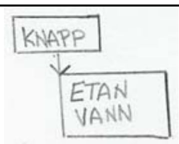
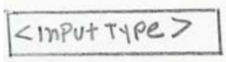
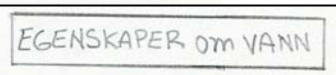
Buttons may contain either text or an image, but not both in the same button. A back and forward button represented with arrows and a home button represented by a house	
A help button with text	
A chart button to display a navigation chart at frame (2)	
A button that displays additional information about important concepts. Or a menu that contains a selection of the most important concepts.	
A rollover textbox that would explain the meaning of all the buttons when pointed at with the mouse.	
A menu for choosing the most important concepts	

Table 11 **Metaphors, Student #2**

7.3.2 Session 2: Drawing the Entry Point of the 3D Scene

The intention with this session was to come up with ideas of how the 3D scene would look and be organized. Session 2 took place between 12:00 am and 2:00 pm. During this session, the students saw some examples of 3D web-based applications developed by Atmosphere [5] available on the Web.
This was not an easy task for them, since drawing 3D scenarios is very complex, they were only asked to draw a general idea of how the main entry point of the 3D scene should look.

Session 2, Student #1

Figure 14 Mock-up 3. General view of the entry point to main 3D scene, Student #1

During this session the students came up with general ideas about how the main entrance to the 3D scene should look. Student #1 drew a bridge and a building on an island as the entry point for the 3D scene (Figure 14). Entry point means, the point that users see when the 3D scene is loaded the first time.

Student #2 also drew a similar mock-up for the general idea of the main entrance to the 3D scene. This can be seen in (Appendix A, Figure 1).

The following section presents the methodology used for designing the 3D prototype.

7.4 Methodology

In this section a detailed presentation of the methodologies used under the design phase of the 3D prototype is presented. The design process is explained step by step with illustrations.

The methodology chosen for the design and development of the 3D prototype was web-based learning as explained under section 5.1. Web-base learning is designed using hypermedia methodology, for this reason, methodology for both web-based learning and hypermedia will be described here.
The following section describes in detail the factors that were taken into account when designing the 3D prototype, such as:

- Navigation
- Orientation
- Speed
- Browsers
- Hypermedia formats
- Interactivity
- User controls
- Support for learning strategies
- Look and style

7.4.1 Navigation

In a web-based learning environment it is very important to get where you want to go. Good navigation means that the user of the web program will not get lost in hyperspace. In order to avoid getting lost in a web application, a number of navigation methods can be applied: Hyperlinks, buttons, menus, and tables of contents.

Hyperlinks
Words, images, pictures, icons, a phrase, or any other object that can be selected can be a hyperlink. There are a number of factors relevant to hyperlinks: for instances; types of links, purpose of links, density, visibility, confirmation, marking, semantic cueing and distance. Each of these factors are explained and illustrated with examples in this section.

- **Types of Links**: Hyperlinks may be words, phrases, text labels, a picture, a movie, an icon or any other object that can be selected. There are advantages and disadvantages for choosing one type of hyperlink over another. For instance, using pictures or images as a hyperlink enhances the visual learning aspect of programs, while decreasing the need for text. The types of hyperlinks included in the 3D prototype are:

- o **Hot words:** have a different colour to the main text, are underlined and cause the cursor to change shape when rolled over, as shown in Figure 15.

Carbon Atom

Figure 15 A hot word link

- o **Images:** This type of link are used for showing images of molecules that can be selected in the 3D scene, as shown in Figure 16 below.

- **Purpose of links**: Links can be used for many purposes; for instance, links may be attached to important information for providing definitions or connecting to related information. Links may be attached to images or objects and be used in a virtual world for exploring concepts. The 3D prototype includes links for key concepts about the subject of carbon chemistry. Links can be attached to key concept words (see Figure 15) in web pages and to images of molecules (see Figure 16) in the 3D scene for exploring concepts.

- **Density of Links:** The number of hyperlinks in a hypermedia program should not be overdone. Too many links may cluster visibility and readability. The amount of links should be considered according to the learner's level. In order not to clutter the screen with many hyperlinks, the 3D prototype includes hyperlinks on the most important key concepts of the carbon chemistry topic. This means that web pages displaying information about a subject should have about 3 to 4 links at most.

- **Visibility, Confirmation and Marking**: Links should be easy to notice, but they should not be distracting to the point that they reduce text readability. Links should not be placed all over the screen, but placed in a consistent screen location. When a link is selected, it should change its visual appearance to show that an action has been performed. The most common type of confirmation used for links is that they become brighter when pointed at. In order to make the hyperlinks easy to visualise, the hyperlinks included in the 3D prototype should have one colour when active, highlighted when pointed at and marked (change colour) when visited.

- **Semantic Cuing:** A semantic cue identifies the relationship between a link and its destination or function; for example, it is common to use an icon of a loudspeaker or an ear next to audial links. The 3D scene includes images with hyperlinks that are not highlighted, but have semantic cues that identify the 3D object as a hyperlink. A blue information sign, as shown in Figure 16, can provide a semantic cue in a 3D scene, indicating that this object can be selected with the mouse pointer.

Figure 16 Semantic cues

- **Distance:** Links can point to pages within the same web site or they may point to external locations, to other web sites. When choosing between local links versus long distance links it is important to inform the user that they are leaving the current site. Long-distance links may not work, a common problem when choosing long-distance links that have been moved to another location. The hyperlinks used in the 3D prototype should only point to local locations within the 3D prototype.

Other object types: There are other types of navigation methods, such as menus, buttons, and tables of contents, maps and picture collections, among others. Menus and buttons are the most common methods of non-linear navigation. Hyperlinks in general should not be used for exiting a program or obtaining help or going to the next page. For this type of navigation, it is recommended to use other techniques such as buttons or menus rather than hot word links.

The following object types were designed and implemented in the 3D prototype:

Images for displaying different types of molecules, as shown in Table 12.

Type of objects	**Function**	**Example**
Images	For visualising images of molecules and other concepts. Similar images were attached to 3D objects in the 3D scene that when selected with a mouse click display VRML models and web pages.	

Table 12 Images of the 3D prototype

The 3D prototype includes buttons with text labels on them for indicating their purpose. All buttons provide confirmation to users. For instance, buttons are highlighted (yellow colour) when pointed at, appear to be pressed or depressed when clicked on (a 3D effect) and are highlighted blue when selected as shown in Table 13. It is important to remark that the 3D prototype includes several buttons that are already included in the 3D player and the VRML browser; these buttons are already part of the applications used in the 3D prototype. The function of these buttons is explained in Tables 17 and 18.

Type of objects	**Function**	**Example**
Buttons	Getting to initial position (home) Getting help Exiting the application Selecting a quiz Navigating back and forward between web pages Printing pages	

Table 13 Buttons

The 3D prototype includes a drop down menu with a “go” button for displaying a choice of key concepts as shown in Table 14.

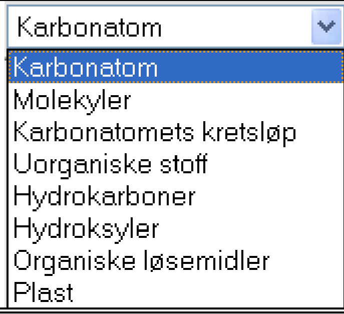
Type of objects	Function	Example
Menus	A drop down menu for showing a list of key concepts from which students could directly select.	

Table 14 Menus

The 3D prototype also includes several tables of contents for classifying and illustrating examples as shown in Table 15.

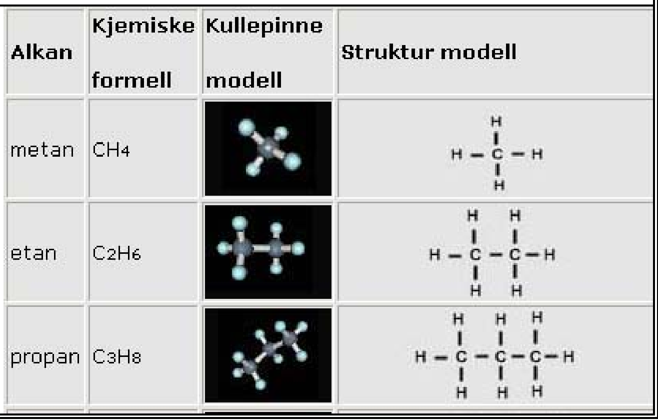
Type of objects	Function	Example
Tables of contents	Displaying information that needs to be categorized and illustrated with different examples and images	

Table 15 Table of content

7.4.2 Orientation

A common problem in web-based instructions is that they do not provide good orientation devices that show the users where they are in the web site. There are many orientation cues that may help to avoid getting lost in hyperspace. The following orientation devices were suggested during the meting on 10.11.2003, with the two students:

- **Navigation Metaphors:** Metaphors may provide a good orientation method in a program. For instance, a lesson or a program can be designed to resemble a house or a building with rooms, where each room will have specific functions. Virtual reality techniques make the implementation of navigation metaphors more realistic and engaging. The 3D prototype used the metaphor of a building (research institute) with several rooms. Each room in the building has a specific function in accordance with the subtopics of the carbon chemistry topic.

- **Frames:** Frames can divide the window in functional areas with different information and purposes, especially when the program has multiple levels of navigation. One frame may display information while another frame may take the user to another location of the program or a location outside the current web site. Using frames gives good control over where the information will appear, while preventing multiple-window disorientation that occurs when clicking to links that display the new information in separate windows. The students suggested dividing the screen into several frames. Their suggestions were taken into account when deciding how many frames the screen layout of the 3D prototype should have. Each frame has different functions and type of navigation. The 3D prototype used frames for the purpose of controlling where the multiple windows of the 3D prototype would appear.

  The screen layout was divided into 4 frames. Under the prototyping sessions (discussed in section 7.3) with the students, 5 frames were suggested, however, dividing the screen in too many frames can make difficult to know which is the active frame. For this reason, the screen layout was divided into only four frames as shown in Figure17.

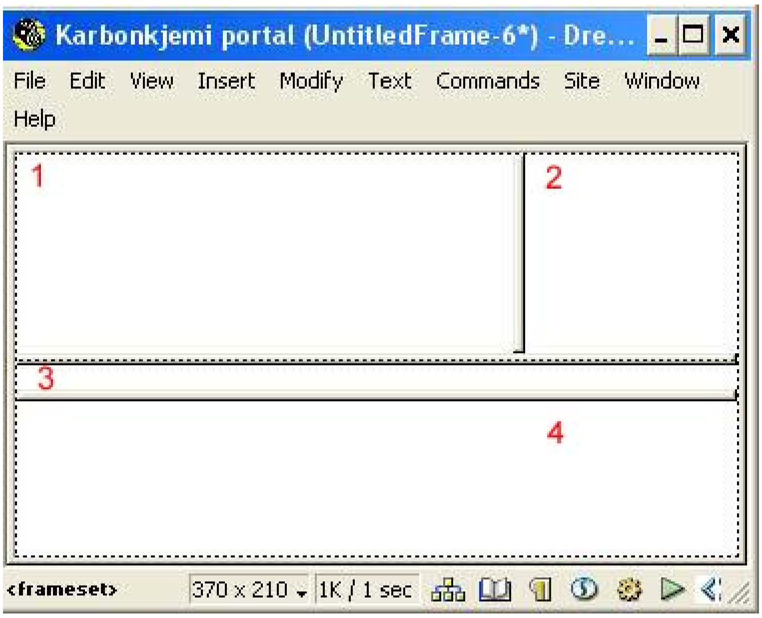


Figure 17 Screen layout of the 3D prototype

- Frame 1: Displays the 3D scene with avatars (Figure 17: 1)
- Frame 2: Displays the VRML browser for displaying the 3D molecules, and information pages. (Figure 17: 2)
- Frame 3: Displays a navigation frame that contains all of the buttons and menus (Figure 17: 3)
- Frame 4: Displays all of the text with conceptual explanations and tables of contents (Figure 17: 4)

7.4.3 Speed

Ytrebygda middle school has a good network communication. It has a bandwidth of 750 kbps. Today's communication speeds vary from 58kbps with modem capability, which is considered slow to 1000kbps with bandwidth capacity, which is considered a medium to fast connection. There are also others connection possibilities such as fibre optical connections that are even faster, but this possibility has not yet been implemented as the standard network connection. Despite the good speed connection, the school's computers had low-speed processors, Pentium III with maximum 500 MHz main processors. Today's personal computers have an average processor capacity of 3 GHz (3000MHz); which today is considered a medium to fast processing speed. This constraint meant that some of the ideas would not be possible to implement. The 3D prototype was developed to the specifications of the slowest speed processor available at the school's computers.

7.4.4 Browsers

A web-based program should preferably be developed in order to run on all type of browsers. Unfortunately this was not possible for the 3D prototype. The 3D prototype is only available for Microsoft Internet Explorer browser version 5.0 or higher. This was due to the limited browser adoption of the Adobe Atmosphere player plug-in that is an essential part of the 3D prototype for displaying the 3D scene. This plug-in is only supported by Microsoft Internet Explorer.

7.4.5 Hypermedia Formats

Taken into account the school's computers processor capacity and the network communication speed, the file formats listed in Table 16 were used in the 3D prototype.

Format	Media supported
JPEG	Images, photos
GIF	Images, photos, animations
MOV (QUICK TIME), AVI	Video, audio, text
AER	3D objects (vector type)
HTML	Text
JSCRIPT	Java Script files
VRML	3D Images, text

Table 16 File formats

7.4.6 Interactivity

Web-based instructions can have many forms for interaction, not only reading text or watching movies, but also other types of interaction that require more active engagement such as, taking a quiz, navigating in 3D worlds with avatars or chatting.

- **Self Test**

  Interactivity is an important feature of hypermedia and multimedia programs. It is a very limited form of interaction if users can only read text, watch videos or listen to audio. Web-based learning programs should support a higher level of interactivity. For this reason the 3D prototype includes self-tests or quizzes related to the topic of carbon chemistry. The students suggested having a quiz inside the 3D scene where they would have to answer some questions in order to proceed to other rooms of the 3D scene. However, since weaker learners may find this too difficult; quizzes were only included at the end of the sections and outside the 3D scene. Figure 18 shows an example of a quiz included in the 3D Prototype.

Figure 18 Quiz

- **Chat Functionality**

Another form of interaction is the chat functionality included in the 3D scene. The learners can chat with one another and discuss the material being presented to them in synchronous time. Figure 19 shows an image of the chat window included in the 3D prototype. The chat window appears in a separate window and can be opened and closed whenever needed.

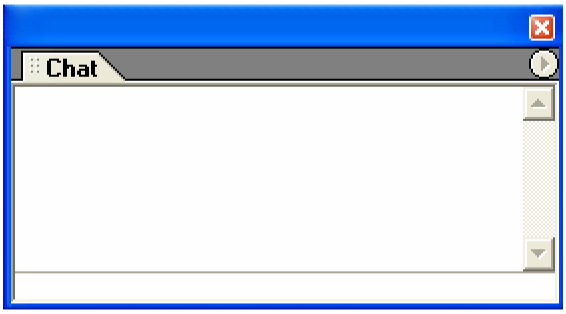


Figure 19 Chat window

- **Avatar Interaction**

The 3D prototype includes avatars that students can choose to navigate with or without inside the 3D world. The avatars available in the 3D prototype vary from human figures, to animals or robot-like figures. The use of avatars required more engagement from the students, since navigation in the 3D world follows the laws of gravity and collision.
Figure 20 shows a set of avatars available in the 3D prototype

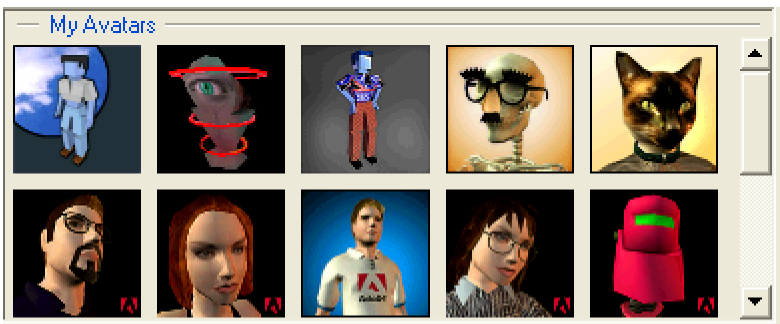


Figure 20 Avatars

- **Direct Manipulation**

Direct manipulation of 3D objects was also included in the 3D prototype. The students can have the opportunity to manipulate 3D objects in the VRML browser, as well as manipulating the movement of the avatars in the 3D world.

7.4.7 User controls

An important feature in web-based and hypermedia learning programs is to give the user the possibility to control the navigation options.
The students may be able to manipulate some of the controls of the 3D prototype.
For instance, the controls included in the 3D player by which the students are able to manipulate avatars and movements inside the 3D scene. Table 17 shows a brief explanation of the controls included in the 3D player.

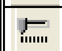
Controls	**Function**
	Setting on and off collisions with objects
	Setting on and off the gravity option which enables the avatars to fly or stay on the ground
	Turn on an off the controls that shows the avatars
	Turn on and off the chat function
	Setting a set of preferences to control movements of the avatars
	Control and set preferences for the 3D scene, such as, acceleration and velocity
	Viewing the users logged into the 3D world
	Choosing and changing avatars

Table 17 **3D player's controls**

All of the buttons of the 3D player have a text box with a description of the button's purpose that appears when pointing at the button, as shown in Figure 21.

Figure 21 **Textbox**

Students may also be able to control and manipulate the shape, speed, angles and size, of the 3D objects displayed in the VRML browser. Table 18 shows all the available controls in the Cortona VRML browser:

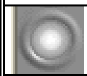
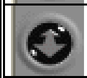
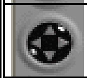
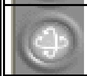
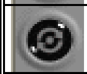
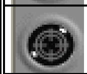
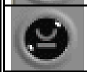
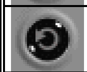
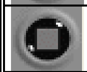
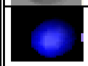
Controls	Function
	Examine
	Plan
	Pan
	Turn
	Roll
	Go to
	Straighten
	Restore
	Fit
	Change Style: To change the shape of the molecules displayed

Table 18 VRML Browser's controls

All of the buttons of the VRML browser have a textbox with a description of the button's purpose that appears when pointing at it, as shown in Figure 22.

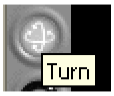


Figure 22 Textbox

Students can be able to control navigation in the web pages, entering and exiting the 3D prototype at any time, as well as getting help about how to navigate in the 3D space. These user controls are available through buttons and drop down menus as explained in Tables 13 and 14. All buttons placed in the navigation frame (see Figure 17: 3) only contained text labels, not pictures. The reason for choosing text labels instead of pictures or icons was because the 3D prototype already included many buttons with pictures as shown in Tables 17 and 18 that come with the 3D player and the Cortona VRML browser. Having more icons added to the 3D prototype could add more cognitive load to the users.

Table 19 shows the buttons designed and placed in the navigation bar:

Controls	Function
START	Entering the 3D prototype
Avslutt	Exiting the 3D prototype
Hjelp	Getting help
Hjem	Getting home
Quiz	Taking a quiz
Neste	Navigating forward
Tilbake	Navigating backward
Skriv ut	Printing pages
Gå!	Selecting a topic from a drop down menu

Table 19 Navigation controls

7.4.8 Support for Learning Strategies

Learning applications should include features that support learning strategies, in other words, to have features that help learners to enhance their own learning, for instance metacognition, orientation and navigation, assessment, visualisation are features that enhance learning (Alessi and Trollip, 2001).

The 3D prototype may facilitate the following strategies; orientation and navigation, assessment, visualization and graphing:

- **Orientation and Navigation**

The 3D prototype may facilitate navigation by providing hyperlinks. The hyperlinks can be activated within the 3D scene. This may prevent the students from getting disoriented in the application, so they can concentrate on the material and not on orienting themselves in the application.

- **Comprehension and Application of Knowledge (Assessment)**

In order to encourage the learners to apply the knowledge they acquired, some techniques were used to support this activity:
The 3D prototype included the following techniques in order to encourage students to apply the knowledge acquired through its use.

  - **Electronic notebooks:** The 3D prototype provides an electronic guest book, where students can post comments. The comments may be answered or posted by the teacher of by other fellow students. This guest book is not a kind of threaded discussion tool.

  - **Self-test:** The 3D prototype has a self-test or quizzes for each sub topic of carbon chemistry topic. The students can take these self-tests to assess whether they learned and remembered some of the material presented.

- **Printouts**: The 3D prototype allows printouts for every web page available. This may facilitate recall and application of knowledge.

- **Visualization and Graphing:**

The visualization of concepts, especially of abstract concepts, may help learners with comprehension process. The 3D prototype provides images, 3D models, 3D objects, animations and movies in order to help learners to visualize abstract concepts.

7.4.9 Look and Style of the Program

This section presents some guidelines for the look and style of the web pages, as well as a description of how the 3D world/scene was divided.

- **Guidelines for Web Pages**

When it comes to font's size, colour and type; headings and background colours of the web pages; the guidelines suggested by W3.org [4] and Lighthouse.org [6] were followed:

- **Guideline 2.2:** Ensure that foreground and background colour combinations provide sufficient contrast when viewed by someone having colour deficits or when viewed on a black and white screen

    - **Contrast:** It is important to have a good contrast between the background colour, the font colours, and the hyperlinks colours.

It is recommended to use colour combinations that have high contrast, such as, light background with dark foreground or vice versa, as shown in Figure 23. One should exaggerate lightness differences between foreground and background colours.

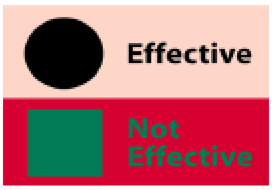


Figure 23 Colour contrast

Based on the guidelines suggested above and after testing the web-site for colour blindness at: http://colorfilter.wickline.org/ and taking into account that 10% of men and 1% of women are colour-blind; the following background and foreground colours were chosen for the web pages of the 3D prototype:

- Black for the foreground text
- Light grey for the background colour of the web pages
- Dark blue for hyperlinks
- Dark violet for active links
- Dark purple for visited links

- **Guideline 5: Fonts:** Always specify a fallback generic font

The following cascade style sheet (CSS) properties were used to control font characteristics like font-family, font size, font colours and font styles in all web pages. The web pages of the 3D prototype use the most common type of font family for the web: verdana, arial, helvetica, sans serif, and all text have 3 levels of headings.

- **Design proposal for the 3D scene (3D world with avatars)**

The 3D scene is divided into the following parts:

- **Main entrance:** Contains objects, images, and information boards about what to find in the 3D scene and which path should be followed, as well as general information about the carbon chemistry topic, for instance, information about carbon atom and different types of molecules representation
- **Room 1 (Inorganic world):** Contains objects and images, as well as, information about inorganic substances
- **Room 2 (Organic world):** Contains objects, images and information about hydrocarbons, hydroxyl molecules and organic solvents. This is a 3D world of its own
- **Room 3 (Synthetic world):** Contains objects, images and information about synthetic substances like plastics and polymers

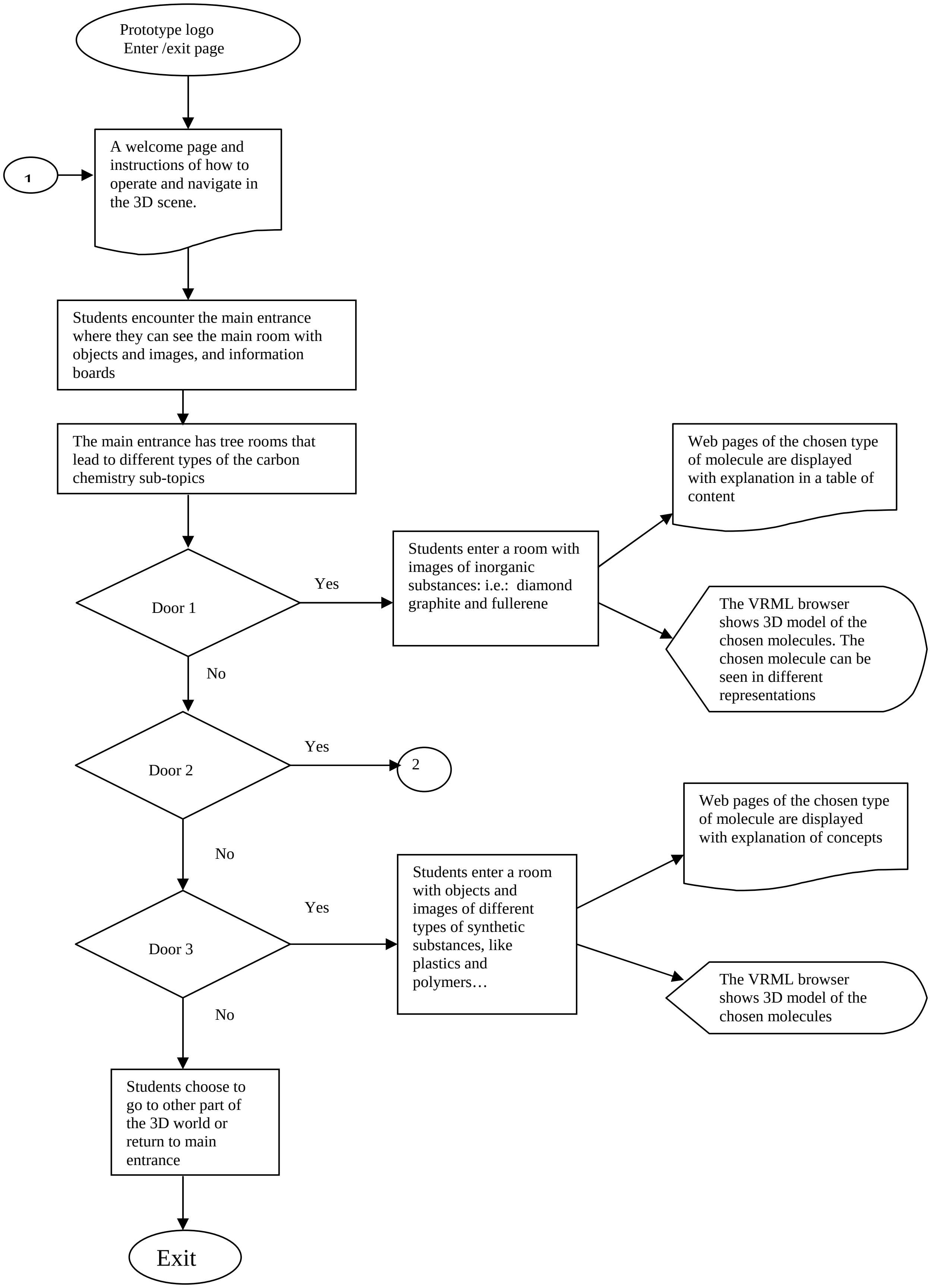
Having discussed the methodologies applied to describe how the 3D prototype would look and what components were included; the next section presents some flowcharts that describe, in general, the sequence of the 3D prototype.

7.5 Flowcharts

There are several types of methods that can be chosen to show the sequence of a program, as for instance, storyboards and flowcharts. Storyboards are a graphical description of the appearance of the intended system without any functionality and are used to show what the users will see in the program. Flowcharts, on the other hand, can be used to show different levels of the program structure and sequence. The levels vary from general sequence to more detailed program descriptions. Flowcharts are not a very useful tool for hypermedia format. However a general description of the main sequences of the program can be depicted by a flowchart without going into details. Storyboards are not very useful for depicting dynamic media, such as animations, videos or 3D environments that include advanced interactions. Because the intended 3D prototype includes both hypermedia formats and 3D animations that are difficult to draw or simulate, flowcharts were chosen as the tool for showing the general sequence of the 3D prototype without going into detail and without drawing screens sequences.

Flowchart 1 depicts the main sequences of the 3D prototype and how the program progresses.

Flowchart 1: The Chemistry World



Comments:

Flowchart 1 illustrates what the students meet when entering the 3D prototype. The 3D prototype starts at a title page with a logo and two buttons, one for entering and one for exiting. Then when entered, they see the 3D scene at entry point. A web page is displayed, welcoming the students. Another web page is displayed with instructions of how to use and navigate the 3D scene with avatars and how to navigate in the VRML browser. When the students enter the main 3D scene, they see three doors that lead them to different part of the 3D prototype.

The main entrance presents the students with information of what they could expect to find in the 3D scene, what is in the three other rooms, and general information about the carbon chemistry topic, like what is a carbon atom and how molecules can be represented. The basic concepts and objects are included in the main entrance. More difficult subjects follow when they enter the other rooms

- Door 1: Leads to room 1 (Inorganic world)
- Door 2: Leads to sub-world 2 (Organic world)
- Door 3: Leads to room 3 (Synthetic world)

- **General Functionality**

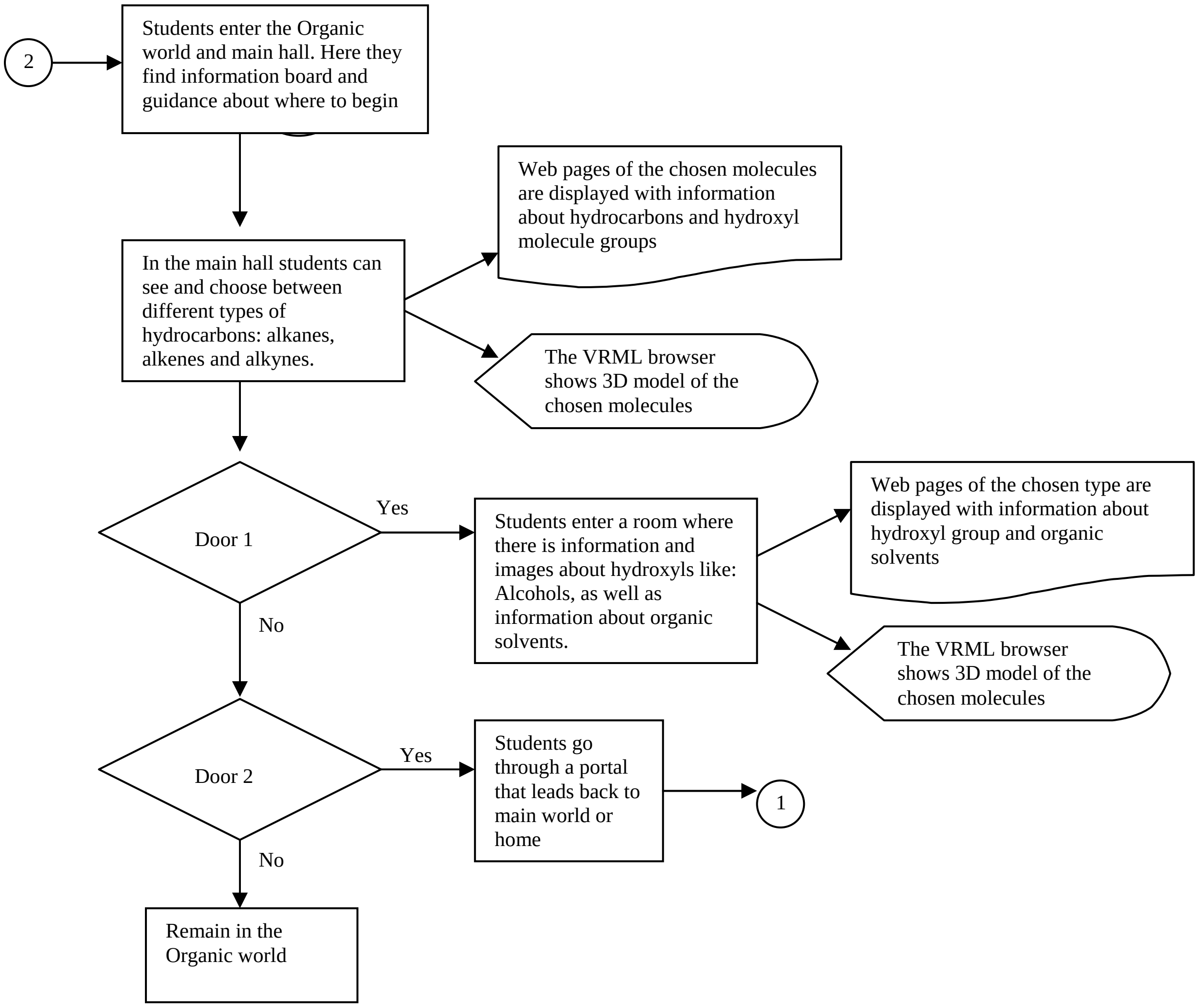
All three sub-worlds have the following functionally:
Objects and images of a topic are shown, when the students select (click with the mouse pointer) on one of the objects or images available, then a web page is displayed, presenting all the information about the chosen object or image. At the same time, the chosen object will be displayed in the VRML browser in 3D format.

Room 1: Contains information about inorganic substances, for instance, graphite, diamond and fullerene.

Room2: Leads to another world (see Flowchart 2) another 3D world of its own. It shows the different types of hydrocarbons and hydroxyl molecules. The hydrocarbons group was sub-divided into three groups: Alkanes, alkenes and alkynes. The hydroxyl room presents information about alcohols and organic solvents.

Room 3: Shows images and objects of the different types of synthetic substances such as plastics and polymers.

Flowchart 2: The Organic World



Comments:

Flowchart 2 shows the main sequence that occurs when students choose room 2 in Flowchart 1, and go to another world. In this case the organic world. Once in the organic world, students see the main hall, which contains information boards and guidance about where to begin. In the main hall there are two doors.

Door 1: leads to a room, which contains information and images about alcohols and organic solvents.

Door 2: is a portal that leads back to the main world.

In this section the following steps were presented: initial content ideas, which implied brainstorming session to describe the topics to be included in the 3D prototype and how the information would be presented. A task analysis was presented to show the sequence of the topics. Prototypes were drawn to come up with ideas of how the screen layout of the 3D prototype should look. A web base methodology was described; which presented all the objects and components to be included in the 3D prototype. This section also presented navigation, orientation, speed, browsers, hypermedia formats, interactivity, users controls, learning strategies, and the look and style that will be implemented in the 3D prototype. Finally flowcharts were presented to show the general sequence of the 3D prototype. The next section presents the development phase of the 3D prototype.

8 Developing the 3D Prototype

The following section describes what was done under development phase of the 3D prototype and how all the steps described under design phase were implemented.

The development phase includes all of the steps necessary to produce the program. This phase includes: programming, choosing tools, writing user manuals, instructions, production of videos, graphics, texts, animations, etc.

During the development phase some of the steps depicted in Figure 10 were followed:

- Preparation of the text
- Writing the program code
- Creation of the graphics
- Production of video
- Assembly of the pieces
- Alpha and beta testing

8.1 Preparation of the Text

The text content of the 3D prototype was produced using Microsoft word processor and then imported into DreamWeaver to add the necessary program code.
Table 20 shows a description of the material and textbooks used to produce the text and content of the web pages.

Resources and tools		**Description**
Text books	Tellus 10 (natur og miljøfag for ungdomssteget)	Provided by Ytrebygda school. This it the textbook used by the school
	Helix 10 Natur-og miljøfag for 10.klasse	An alternative textbook for teaching of natural science
	Læreplanverket for den 10-årige grunnskolen, 1996	Provided by Ytrebygda school
Multimedia programs	Microsoft Encarta 2000 Encyclopaedia	CD-room
	MOLECULES Molecular modelling for chemical education	A web-based tutorial by the Lebanon Valley College Available at: http://www.molecules.org/

Table 20 Text materials

8.2 Program Code and Tools

The programming language used to implement the 3D prototype was JavaScript, VRML and HTML. In order to implement the code on the computer, the following tools were used (see Table 21).

Tool	Function
Adobe Atmosphere Builder 1.0 Build 198	Used to create the 3D scene
Adobe Photoshop 6.0	Used to create and edit the graphics
DreamWeaver 3.0	Used to create all web pages and write JavaScript code into the pages
Image ready 3.0	Used to edit video (avi and mov files) for the movies inside the 3D world
Notepad	Used to write JavaScript code to be included in the 3D world, to write VRML code, to create and edit PDB files

Table 21 Developing tools

All web pages were produced using Macromedia DreamWeaver 3.0
JavaScript code was included in most pages to code the function behind user controls like buttons, drop down menus and quizzes.

8.2.1 Adobe Atmosphere Builder 1.0

Adobe Atmosphere Builder 1.0 was used for building the 3D scenes. This tool is highly functional for building virtual 3D worlds and also offers the possibility to publish them on the Web. It provides support for real-time avatar chat for up to 20 simultaneous participants, a well-developed design environment and support for Java script, giving the possibility of hyper linking, animation and movie playback, among other features.

The following section describes briefly how the 3D prototype was built using Atmosphere Builder:

Atmosphere Builder provides tools for creating basic geometric forms such as boxes, floors, polygons, walls, slabs, stairs, columns, and cones. Besides these basic geometric forms, one can also combine two or more objects to create a new one. Combination of 3D objects can be done by:

- Union: Creates a composite object
- Intersection: Creates an object from the junction of two or more objects
- Subtraction: Creates openings in objects

All objects created in Atmosphere Builder can have textures and colours. It is also possible to add more dynamic effects to 3D object by using Atmosphere JavaScript API (Application Program Interface). The following API functions were used for the 3D prototype:

- To create an entry point: an entry point is the location that users will first see when entering the 3D world (see Figure 30)

- To create a Portal: a portal is a link from one 3D environment to another 3D environment. Portals are used to exit one environment and entering another. The 3D prototype has a portal to the organic world (see Figure 24) where the avatars enter a new 3D scene or world (see Figure 33)

Figure 24 The portal to the organic world

- To create links: It is possible to add links to objects within a world using JavaScript. JavaScript was attached to some of the 3D object that when clicked, displayed a web page, see Figure 25.

Figure 25 A 3D object that displays a web page

- To create 3D image links: JavaScript were attached to 3D objects with molecular images, that when clicked, displayed a 3D model in the VRML Browser, see Figure 26.

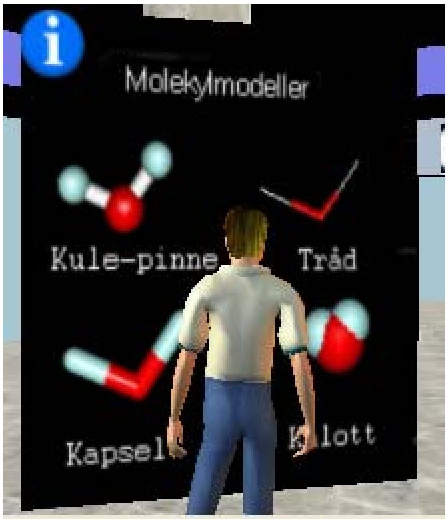


Figure 26 **Links attached to images**

- To add animations: It is possible to add movies of type .mov, avi, and mpeg to an object in a 3D world. Some videos files were attached to 3D objects that displayed a movie in the 3D world, see Figure 27.

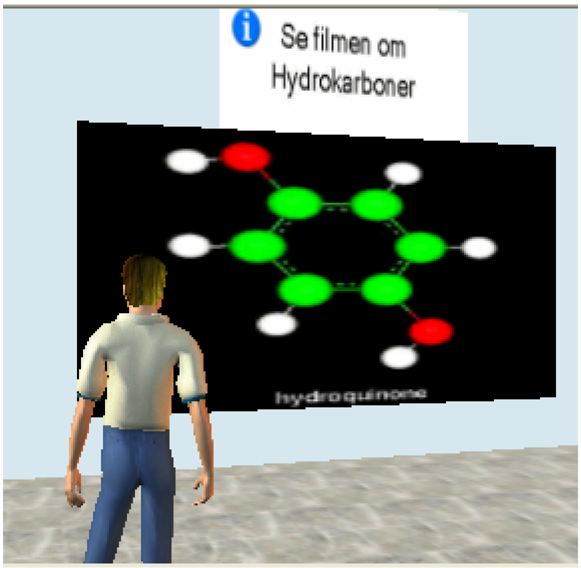


Figure 27 **Film about hydrocarbons**

8.2.2 The Construction of the 3D World

Atmosphere Builder provides different perspective to view the objects under construction. Figure 28 shows the 3D prototype under construction.

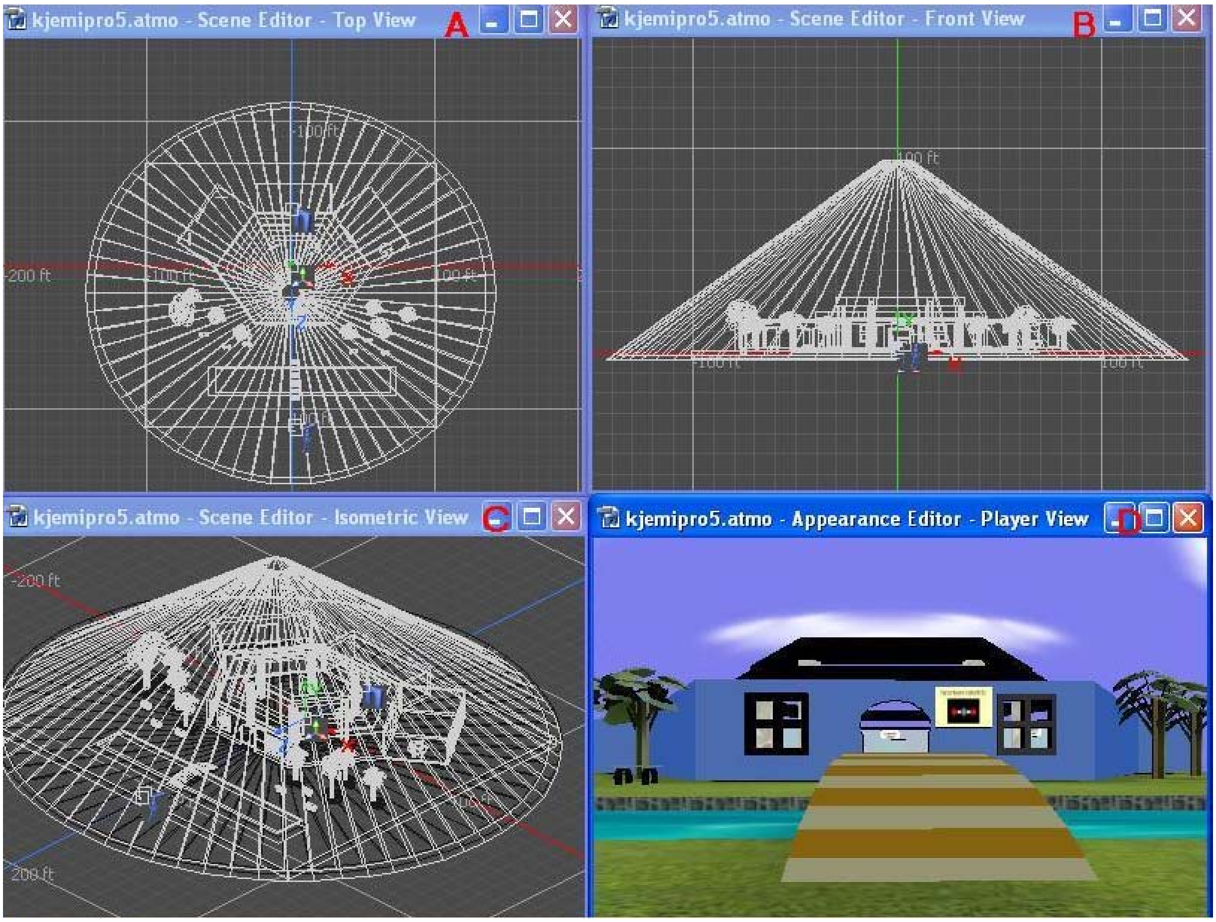


Figure 28 **The 3D prototype under construction**

The different views show the lines that make up edges of objects from different perspectives, for instance: top view (Figure 28: A), Front view (Figure 28: B), isometric view (Figure 28: C); among other available views, and are used to create and edit the geometry of objects. The player view (Figure 28: D), shows the scene, as it appears in the web browser when the users enter the world.

8.3 Creation of the Graphics

When creating graphics, it is important to take into account the medium in which the 3D prototype will be used. The processor capacity/limitations of the schools computers (see Appendix A Tables 1 and 2) and the time it will take to load all the files were taken into account when creating the type of files and quality of the graphics that could be loaded and displayed quickly.

Adobe Photoshop 6.0 was used to create all the graphic files.

The file size was set to medium (approximately between 5kb to 10kb) as well as the quality of all images included in the 3D scene and in the web pages. The types of graphic file formats used in the 3D prototype were: jpeg and gif.

8.4 Production of the Videos

Both videos and animations were edited and created using Adobe Image Ready 3.0
Two videos were edited and one animated gif was created:

- A video showing the structure of a carbon atom. This video was included in the main entrance of the main 3D scene (see Figure 31: D)
- A video showing different types of hydrocarbons. This video was placed in the organic world (see Figure 27)
- An animation of a cyclopentane molecule placed in the title page of the program (see Figure 29)

8.5 Assembly of the Pieces (The Rendered 3D Prototype)

After all the pieces of the program were produced, they were put together to create the 3D prototype. The following section shows the 3D prototype and how it was assembled.

8.5.1 The Title Page

All programs should have a title page to inform the users what the program is about, to give information about the author of the program, and to provide a way of entering or exiting the program. Figure 29 shows the title page with an animated logo. The title page has two buttons, one for entering the 3D prototype and one for exiting.

Figure 29 **The title page**

8.5.2 The Entry Point of the 3D Prototype

When users choose the start button at the title page (Figure 29), the following 3D scene is displayed as shown in Figure 30 below:

Figure 30 The entry point of the 3D prototype

The screen is divided into 4 frames:

Frame A: displays the entry point of the 3D world and all 3D scenes (Figure 30: A)
Frame B: displays information pages / and VRML molecules (Figure 30: B)
Frame C: displays a navigation bar with buttons and menus (Figure 30: C)
Frame D: displays web pages with content about carbon chemistry topics (Figure 30: D)

The welcome page shown in (Figure 30:D) informs the users of the general purpose of the program and how the program is composed and works. Frame B displays help information about how to navigate in the 3D scene with avatars and how to manipulate the 3D models displayed in the VRML browser.

8.5.3 The Main Hall of the 3D World

As discussed in section 7.5 (Flowchart 1 and 2) the 3D prototype is divided in four parts or worlds

- The main entrance
- The inorganic world/room 1
- The organic world/ room 2
- The synthetic world/room 3

8.5.4 The Main Entrance

The main entrance to the 3D world contains graphics and general information about carbon chemistry topic, atoms and molecules, as shown in Figure 31.

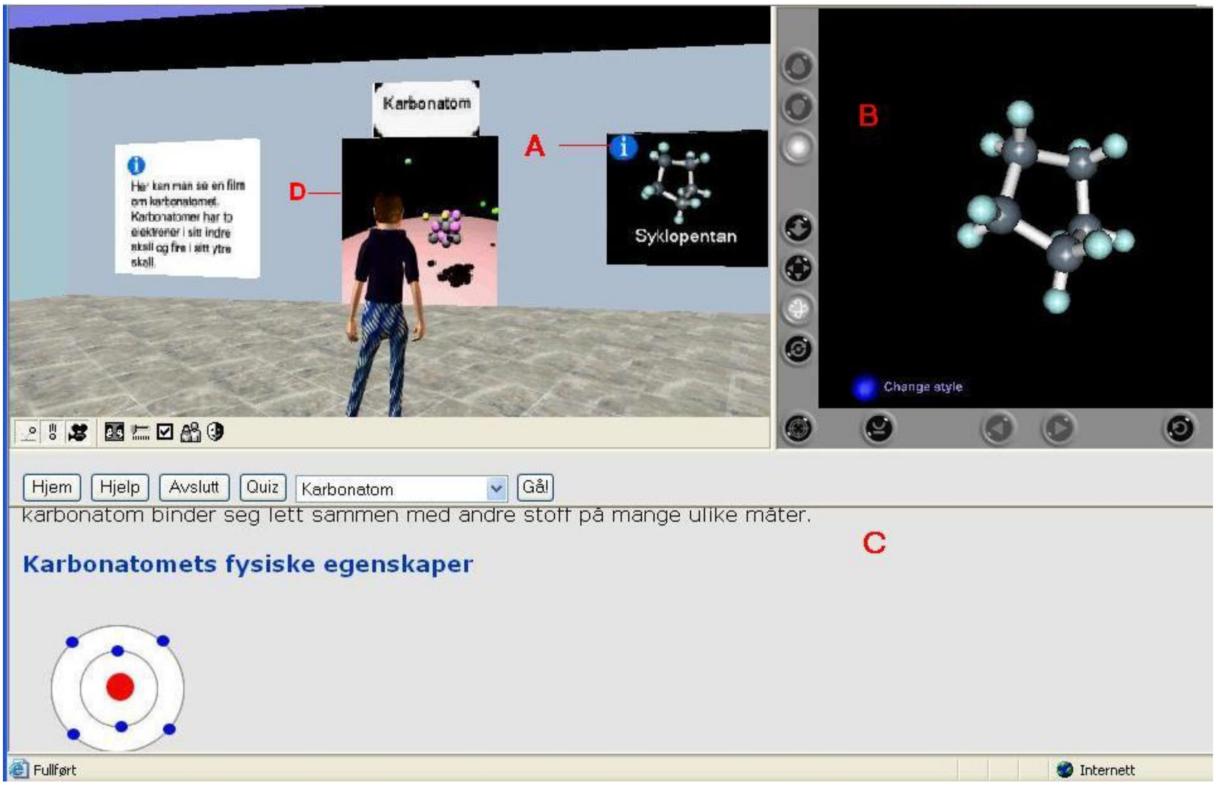


Figure 31 The main entrance

All signs inside the 3D scene have an information sign like this one:  (Figure 31:A) meaning that the sign can be selected. When the users select a sign with a molecular image on it, the 3D model of the molecule is displayed in the VRML browser (Figure 31: B), and a web page with information about the molecule is displayed in the information frame, (Figure 31: C). The avatar is looking towards the movie about carbon atom (Figure 31: D)

8.5.5 The Inorganic World

Inside the inorganic room there are images of molecules related to the topic of inorganic chemistry, as shown in Figure 32. In this room, students can select images about inorganic substances, such as carbon dioxide, diamond, fullerene, etc.

Figure 32 The inorganic world

8.5.6 The Organic World

In order to get to the organic world, the avatars have to go through a portal as shown in Figure 24. Once the avatar has gone through the portal, a new 3D world that resembles an institute research building is displayed as shown in Figure 33.

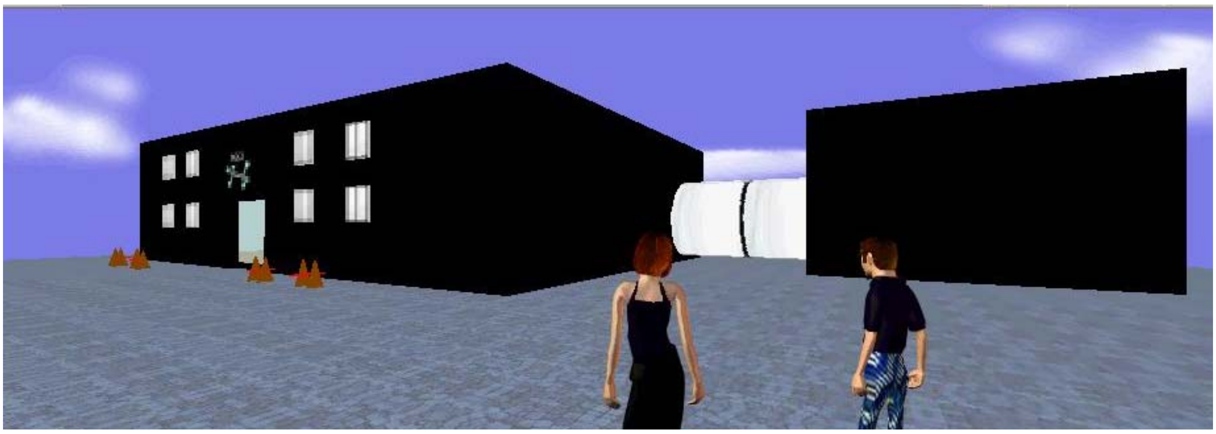


Figure 33 The entry point of the organic world

Inside the organic world, users can find information about the topic of organic chemistry, hydrocarbons and organic solvents. There are also information boards that indicate what direction to start with. A movie about different types of alkanes is shown behind the avatar see Figure (34: A)

Figure 34 The main hall of the organic world

8.5.7 The Synthetic World

The last part of the 3D prototype is dedicated to the synthetic world, inside this room; the students can find information about plastic substance and their uses as shown in Figure 35

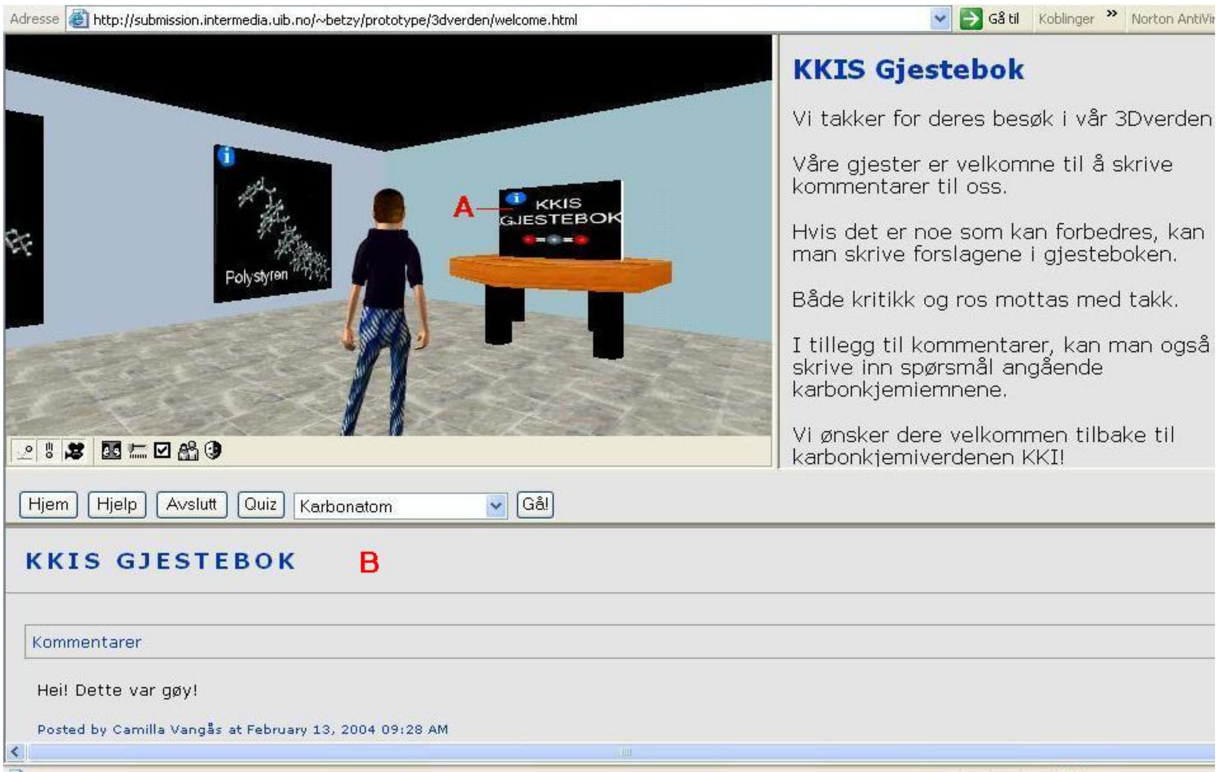


Figure 35 The synthetic world

In this room, as in the others, the user can select a sign with a molecule on it, and then a VRML model of the chosen molecule will be displayed in the VRML browser.
Inside this room there is an electronic guest book (see Figure 35: A) that when selected, an electronic book for writing comments and questions is displayed in the information frame (Figure 35: B).

Other features implemented in the 3D prototype are:
A navigation bar: (Figure 36: A) with buttons and menus and the possibility to assess learning by taking a quiz about the three topics of carbon chemistry.

Figure 36 The navigation bar

The students may choose the quiz button in the navigation bar (Figure 37: A), then 4 type of quizzes based on subtopics of carbon chemistry can be chosen (Figure 37: B). The chosen test is displayed in the information frame (Figure 37: C). Finally the points are displayed in a pop-up window (Figure 38: A).

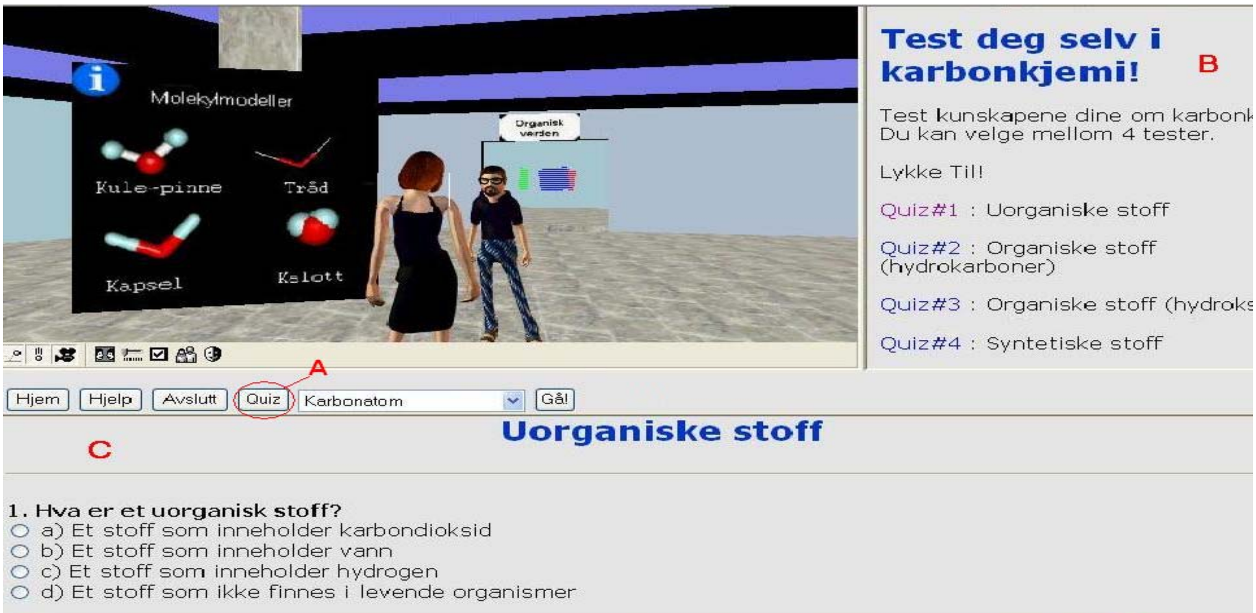


Figure 37 Taking a quiz

Figure 38 **Taking a quiz, the results**

8.6 Alpha and Beta Testing

The purpose of alpha testing is to go through the program to evaluate the content, the program's flow, strength and weaknesses and to identify errors. Beta testing is the full or final test of the program before deployment; the purpose behind a beta test is to discover usability problems. The beta test is performed with end-users. Alpha and beta testing are also referred to as formative evaluation and will be explained in detail in the evaluation part of this thesis.

In this section the following steps were presented: Preparation of the text, which implied writing the content of the web pages. The program codes and tools used to implement the 3D prototype were explained in details. The graphics and videos produced were discussed. Finally the whole 3D prototype was presented with screenshots from the running program.

The following section of the thesis presents the evaluation part of the 3D prototype.

9 The Evaluation

This part of the thesis starts with a discussion of the theoretical framework and methods that the evaluation part tries to follow. First, a discussion of Human Computer Interaction (HCI) and aspect of usability and heuristics principles is presented. Second, a discussion about formative evaluation is presented. Section 10 presents the plans and goals of the evaluation. Section 11 discusses the methodology and data collection methods and section 12 presents data analysis. Section 13 presents a final discussion and conclusions.

9.1 Human Computer Interaction (HCI)

Broadly speaking, the field of Human Computer Interaction (HCI) concerns interactions between humans and computers. In its early stages, this field was called Man-machine Interaction. HCI also called as Computer-human Interaction (CHI). It is a multi-disciplinary subject that covers disciplines including psychology and cognitive science, in order to understand user's perceptual and problem solving skills; ergonomics for understanding the user's physical capabilities; sociology for understanding wider context of interaction; computer science and engineering to be able to build the necessary technology (Dix *et al.*, 1997). So in order to design good interactive systems a combination of all these disciplines should be gathered in a design team.

HCI has four major focuses: 1. the users, 2. interactions between users and the system, 3. the system and 4. usability aspects. The users must be understood as an individual or groups of people using a system. The system may be a desktop or a larger and complex computer system. Interactions are performed on the system in order to accomplish a task. The fourth focus is on usability; this implies designing computer systems in such a way that users' interaction with the systems is perceived as supportive when accomplishing some task rather than a hindrance. In other words, the computer systems must be user friendly and follow a set of usability principles.

9.1.1 What is Usability?

The term usability comes from the term user friendly that is traditionally associated with the attributes of learnability, efficiency, memorability, errors and satisfaction.

- **Learnability**: The system should be easy to learn so that the user can rapidly start getting some work done with the system

- **Efficiency**: The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible

- **Memorability**: The system should be easy to remember, so that the casual user is able to return to the system after some period of not using it, without having to learn everything all over again

- **Errors**: The system should have a low error rate, so that users make few errors during their use of the system, and so that if they do make errors they can easily recover from them, and further catastrophic errors must not occur

- **Satisfaction**: The system should be pleasant to use, so that users are subjectively satisfied when using it

Usability is measured by having a number of test users (selected to be as representative as possible of the intended users) use the system to perform a pre-specified set of task (Nielsen, 1993).
Jakob Nielsen and Rolf Molich (1993) proposed 9 usability heuristic principles that can be applied when performing usability tests. Nielsen alters the set of heuristics principle in 1994 adding one more principles to the list. Table 22 presents a list of 10 heuristics principles associated with usability:

Usability Heuristics Principles

Simple and natural dialogue: Means that no irrelevant or rarely used information should be presented in the system. All information should appear in a natural and logical order. Information and operations should be accessed in a sequence that matches the way users will most effectively accomplish a task. Keep to the principle that less is more, this mean that every time a new feature is added to the system, there is one more new thing for users to learn
Speak the users' language: All dialogues should contain words and phrases familiar to the user. It is not recommended to use technical or system-specific terms. There should be a mapping between computer concepts and user concepts with words, phrases and concepts familiar to the user. Keep to the user's native language and avoid using terms or words in a foreign language if possible. Metaphors can be a good way to achieve a mapping between the system and the real world
Minimize the users' memory load: Users should not have to remember information from one section to another. Information about the system use should be visible and easy to retrieve. System interface should be based on recognition, make objects, actions and options visible whenever needed
Consistency: Action, situations in one part of the system should mean the same in other parts of the system. It is recommended to use standards and conventions. The same command or the same action should always have the same effect. Information should be presented in the same location on all screens and it should be formatted in the same way
Feedback: Users should get a clear response from the systems when an action takes place. Users should be informed about the status of the system, informing the users about what is taking place and how user's input is interpreted. The system should give feedback about response time, how long an action will last, about system failure and errors
Clearly marked exits: Users should not feel trapped by the system. The system should provide an easy way to exit or escape, or to undo actions in order to bring the system to a previous state. Exit and undo mechanisms should be made visible in the interface and should not depend on the user's ability to remember some special code or combination keys

Shortcuts: Accelerators may speed up the interaction with the system for expert users. Experienced users should be able to perform operations in a faster way, by using dialogue shortcuts. For instance, the system can have function keys that can perform and action with only a key press (F7 for help) or having buttons to access important functions directly and quickly. Users should be allowed to jump directly to a desired location of information. Large amounts of information should have a backtrack feature to allow the user to return directly to prior locations
Good error messages: Errors should be explained precisely, indicating the problem and suggesting a solution. Error message should be phrased clearly and simple so that they are easy to understand. They should help the user to solve the problem
Prevent errors: A system should be designed to prevent errors from occurring in the first place. Avoid building modes and similar commands into the system, because they are a source of errors
Help and documentation: These should be provided and should be easy to search, be focused on the user's task and not be too large. Systems should have a manual and online documentation with search facility. Help documentation should be structured and it should be easy to find, read and understand. Help documentation should be provided with examples and graphics rather than abstract descriptions

Table 22 Usability heuristic principles

9.2 Formative Evaluation

Why formative evaluation?

Formative evaluation helps the designer of a product, during the early development stages, to increase the likelihood that the final product will achieve its stated goals. Evaluation in this definition means the systematic collection of information for the purpose of making informed decisions to improve the design of the product. The term formative indicates that information is collected during the formation of the product (Flagg, 1990).
Formative evaluation refers to the process of gathering information to advise design, production and implementation decisions. The main reason for performing formative evaluation is to inform the decision-making process during the design, production and implementation stages of an educational program with the purpose of improving it (Flagg, 1990).

According to Martin Tessmer (1993), the term 'Formative' is used in a developmental sense. The evaluation target is instruction in its formative stages, instruction that is developing and not yet finished. The term 'Evaluation' is a data gathering process to determine the worth or value of the instruction, of its strengths and weaknesses. The identified strengths and weaknesses are used to revise the instruction to improve its effectiveness and appeal.

There are two major evaluation types for user interface, formative and summative. Formative evaluation is performed to help improve the interface during the development stage. In contrast, summative evaluation is used on systems that are already completed and at its final stage.
The purpose of summative evaluation is often comparative and aims at assessing the overall quality of an interface.

The reason for choosing formative evaluation is because the 3D prototype is not a finished product and it is only a prototype that is still under development.

9.2.1 The Model: Layers of Formative Evaluation

Tessmer (1993) proposed the following layers for performing a formative evaluation

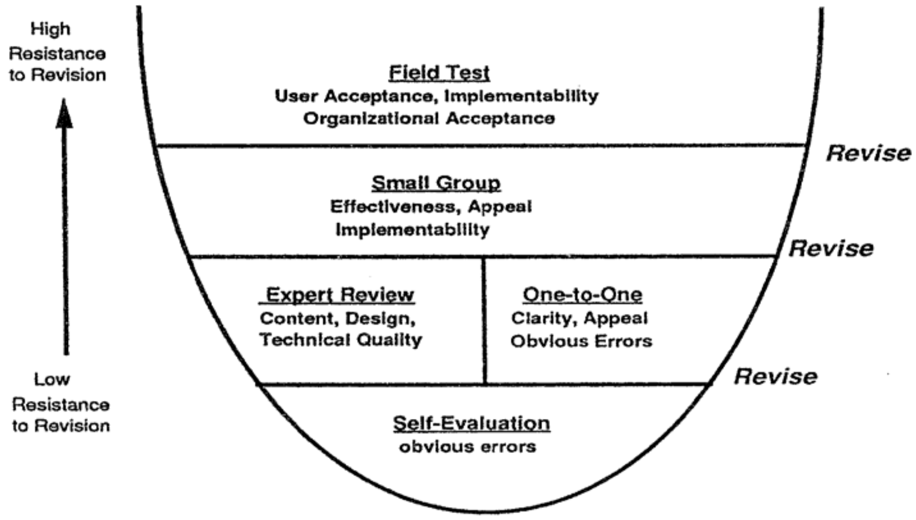


Figure 39 **Layers of formative evaluation**

- **Expert review**: This stage involves an expert reviewing the instruction with or without the evaluator. The instruction is evaluated to review the content accuracy. Expert reviews are done in the first stages of the formative evaluation and the evaluator sits with the expert and reviews the instruction together

- **One-to-one evaluation:** This stage involves one learner reviewing the program with the evaluator. The evaluator sits with the learner and observes how the learner uses the instruction. The evaluator may question the learner during the evaluation and then at the end of the evaluation. The major goals for this review is to get information from the point of view of the learners, when it comes to ease of use, learner performance and satisfaction, clarity of the instructions, appeal, and usability problems

- **Small group evaluation:** this stage involves a group of learners reviewing the program. The evaluation takes place in an environment that is similar to that in which the program will be used in a realistic manner. The group of learners may be given entry tests, pre-tests, post-tests and will be debriefed at the end of the evaluation. The main goal of performing a small group evaluation is to discover the strength and weaknesses of the instruction so the primary purpose is to improve the instruction

- **Field test:** This stage involves evaluating the instruction in the same environment in which it will be used. The purpose of field-tests is to confirm the revisions made in previous evaluation stages. To make general revision suggestions and to investigate the effectiveness of the instruction

This section presented the theoretical framework for the evaluation of the 3D prototype. The following steps were discussed: Human Computer Interaction, usability methods, heuristic principles, formative evaluation and layers of formative evaluation. The next section presents the planning phase of the evaluation.

10 Planning the Evaluation

According to Tessmer (1993) before starting an evaluation, the following questions should be clarified: What are the goals of performing the evaluation? Who will take part of the evaluation?, How many evaluation stages will be carried out?, What methods and tools will be employed for data gathering?

10.2.1 Goals of the Evaluation

The reason for undertaking a formative evaluation, in this project, is connected to the research question:

What kind of design problems will arise from a formative evaluation of the 3D prototype?

The evaluation will have the following goals:

- **Locate ease of use problems**: This goal focuses on usability aspects of the 3D prototype. For this purpose, a usability test was performed to find out usability aspects such as: ease of use, user control and freedom, consistency and standards, feedback, navigability, help and documentation

- **Evaluate content quality**: The content of the 3D prototype was evaluated by: content accuracy, completeness, narration, logical sequence, match to learner's level, curriculum fitness and appeal of the instruction. For this purpose an expert review was conducted with one teacher

10.2.2 The Number of Subjects

Figure 40 shows the proportion of usability problems found in accordance to the number of subjects involved. This Figure shows that there is an advantage using more than one subject. Nielsen (1993) recommends using about five subjects and at least three for performing a usability test. The amount of usability problems discovered in an evaluation increases according to the number of subjects that participates in the evaluation. However, as shown in Figure 40, one should not use a large number of subjects, since the amount of usability problems found flattens when using more than 15 subjects. For this reason, only 6 subjects will participate in the usability test of the 3D prototype.

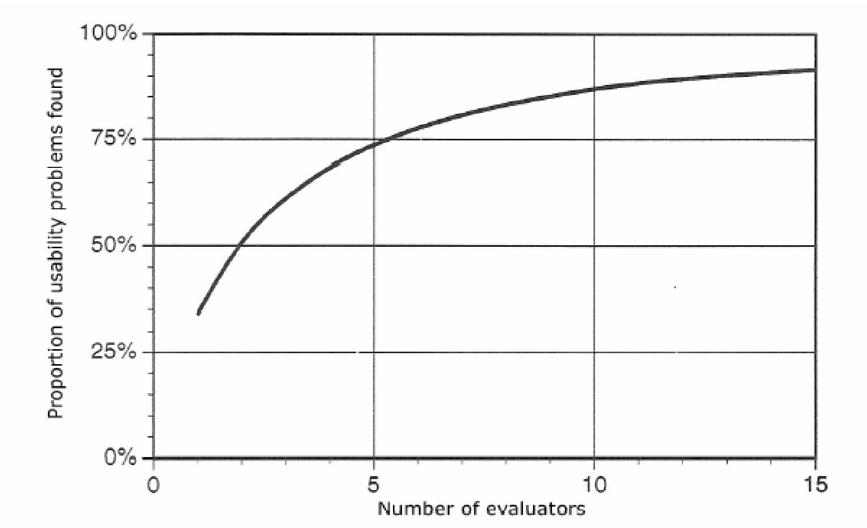


Figure 40 **Number of evaluators**

The Figure shows the average results from six studies discussed by Nielsen (1993)

When choosing the subjects for the evaluation, it is also important to consider the differences between novice and expert users. According to Nielsen (1993), almost all user interfaces need to be tested with novice users and should also be tested with expert users.

10.2.3 Layers of the Formative Evaluation

Based on Tessmer's (1993) model of layers of formative evaluation (see Figure 39), the following stages were carried out:

- **Expert review:** The teacher is a valuable instructional expert because they can best evaluate the fit of the instruction to its intended context (Tessmer, 1993). The teacher actively participated in the expert review, and helped to review the content of the 3D prototype. The major goal for expert evaluation was to review the quality of the content

- **One-to-one evaluation**: Two students and four middle school teachers reviewed the 3D prototype. The major goal for this review was to discover usability problems with a focus on: ease of use, user control and freedom, consistency and standards, feedback, navigability and system help. In order to get this information, a usability test was performed taking into consideration some of the heuristics principles listed in Table 22

10.2.4 The Evaluation Settings

The setting for the one-to-one evaluations where two students took part, was the school's multi-media room at Ytrebygda middle school. There was one PC with a good processor capacity (Pentium III, 500MHz) and a good graphic card and bandwidth connection speed of 100mbps.

The PC available at the multi-media room fulfilled all the specified system requirements necessary to run the 3D prototype as explained in section 6.3. All the extra necessary software was installed on that machine with authorization of the teacher, Helga Sunde on 13.02.2004 one hour before meeting with the students.

The setting for the expert review and the others one-to-one evaluations with four different middle grade teachers took place at the teacher’s offices or homes. The pc available and the system requirements for running the 3D prototype was checked and installed before performing the evaluations.

The next section presents the methodology used to perform the formative evaluation.

11 Methods

In this section a brief discussion of usability methods is presented, followed by a description of the methods used for gathering data for the usability test.

Quantitative Methods: Were originally developed in the natural sciences with the purpose of studying natural phenomena. Laboratory experiments and numerical and statistical methods are examples of quantitative methods (Myers, 1997). Data gathering methods are structured and include a larger selection of subjects. Subject selection is representative of the population under research. Findings and conclusions are presented using numerical and statistical analysis. Interviews and questionnaires are quantitative methods as long as they are designed with predefined answer alternatives.

Qualitative Methods: Qualitative methods were developed in the social sciences to study social and cultural phenomena (Myers, 1997).
Qualitative methods studies do not focus on numerical data and only take into account a small number of research individuals which gives more time to use on each individual and this give more qualitative quality to the collected data. One downside of qualitative methods is that because the research is based on a small sample from the population, the results cannot be generalised. Among the most used qualitative data gathering methods are: interviews, document analysis, observation and questionnaires.

For the evaluation of the 3D prototype a qualitative approach was chosen. The reason for choosing a qualitative research approach instead of quantitative is because the evaluation is based on a small sample from target users (only 6 subjects participated in the evaluation) and this is not representative of the target users population. In addition, the goal of the evaluation, which is to locate design problems through a usability test, does not require involving many users. According to Myers (1997) it is the goal of the evaluation that determines whether research should be quantitative or qualitative.

11.1 Usability Methods

There are several methods to choose from when evaluating the usability of a system. For instance: heuristic evaluation, cognitive walk-through, thinking aloud, observations, questionnaires and interviews, among other methods. All these usability methods are formative, meaning that the system to be evaluated is under development and the evaluation is used to discover usability problems that can be corrected as a part of an iterative design process. Briefly, heuristic evaluation is accomplished by looking at an interface and trying to come up with an opinion about what is good and what is bad about the interface (Nielsen, 1993). A set of heuristic rules or principles is used in order to come up with a critique of a system and discover potential usability problems. Cognitive walk-throughs require a set of detailed reviews of a sequence of actions to be performed by the evaluators, the sequence of actions refers to the steps that an interface will require a user to perform in order to accomplish some task. The main focus of a cognitive walk-through is to establish how easy a system is to learn (Dix. *et al*., 1997). Thinking aloud involves having a test subject use the system while continuously thinking out loud and verbalizing their thoughts thus making it easy to identify users' major misconceptions (Nielsen, 1993).

The principles of ***validit***y and ***reliability*** should be noted no matter which method is chosen to gather data. Reliability is about whether the same results can be reached if other researchers repeat the test. Validity refers to the question of how well the gathered data reflects the research question or hypothesis of the study in question.
When it comes to usability methods, these two principles are a downside of these methods. The reliability of usability tests is a problem due to the enormous individual differences between test users (Nielsen, 1993). If other researchers were to repeat the same test, but using other users, it is not probable that the same results can be reached.
Validity of usability tests may arise some problems involving using the wrong users or giving the users the wrong task, which again will give wrong results.

Observations

Observations are the simplest of all usability methods since it involves observing the users while using the system. Users are asked to complete a set of predetermined tasks and the evaluator watches and records or takes notes of the user's actions (Dix. *et al*., 1997).
One advantage of observing users doing their tasks is that one often finds that they use the software in unexpected ways (Nielsen, 1993). However, simple observation is not sufficient to discover all usability problems since this method does not give insight into users conceptions of the system.

Questionnaires

Questionnaires are an alternative method for gathering information from users. This method is less flexible than interview and observation, since questions are fixed in advance. One of the major advantages of questionnaires is that they can be administered to many users, they takes less time to be filled and can be analysed more rigorously. The questions should be designed in advance and very well since subjects do not have the opportunity to clarify whatever might be unclear about the questionnaire. Different types of questions may be posed, such as: general questions, multi-choice, scalar and open-ended.

Interviews

Interviews are good tools for gathering information about user's opinions, preferences, impressions and experiences. Interviews are methods to gather information in a direct and structured way. They provide a direct way to ask users about their experience with a system, what they like or dislike, whether the system was easy or difficult to use. Interviews should be planned and designed with a set of prepared questions. Another advantage of interviews is that the questions asked to the users can be further explained and clarified, and the evaluator can ask for a more detailed answer or ask the users to give further explanations of interesting issues as they appeared. The level of questioning can vary to suit the context. Interviews that are undertaken immediately after an evaluation section give the users the opportunity to reflect upon what they had just experienced. One major disadvantage of interviews is that they are indirect methods; since they do not study the user interface itself but only users' opinions about the user interface (Nielsen, 1993).

11.1.1 Data Gathering Tools

The following methods and tools will be used to gather data during the formative evaluation:

- Observation
- Interviews
- Questionnaires

These methods will be used in the following stages of formative evaluation:

Formative evaluation stage	Method	Data gathering tools	Evaluation goals
Expert review	Interview	Prepared questions	The content accuracy, fitness, completeness and quality
One-on-one evaluation	Interviews Observations Questionnaires	Audio recorder Recording log Notes Prepared questions	Discover design problems by performing a usability test

Table 23 Data gathering methods and tools

The tools used for the interviews and observations are:

- Audio recorder (mini-disc)
- Record logs (prepared questions)
- Notes

Each subject was asked if they would allow their interview to be audio-recorded. All subjects consented.

Under this section the following steps were discussed: Usability methods for performing the usability test, data gathering tools and methods. The next section presents the data analysis of the evaluation.

12 Data Analysis

In this section the results from the expert review and one-to-one evaluations are presented first, followed by a discussion of all the results from the usability test, taken into account the heuristic principles suggested by Nielsen (1993).

12.1 Expert Review

Expert reviews are done with a specialist that has experience and knowledge with regard to the content being evaluated. In this case, the teacher of the class, Helga Sunde who teaches the natural science curriculum at Ytrebygda middle school for the 10^{th} grade is a subject expert and a valuable expert with regard to the content being evaluated for the 3D prototype.
The expert review was performed at the teacher's home on 09.01.2004. The teacher's personal computer had all the software and hardware necessary to run the 3D prototype. She had installed the Atmosphere player and the Cortona VRML browser in her computer some months before the expert review took place, since she was revising the 3D prototype as content was delivered to her. The expert review took 2 hours. During the expert review, notes were taken while the teacher was revising the content of the 3D prototype on line. The teacher was asked questions at different points of the evaluation. The questions asked to the teacher were predefined and are given in Appendix B.

Goals of the Expert Review: The goal of the expert review was to evaluate the content quality of the 3D prototype. For this purpose, the information sought from the review was divided in two major types:

- **Content information:** Evaluate the content completeness, accuracy, logical sequence and narration level
- **Teaching information:** Evaluate the match of the content to learner level, curriculum fitness and appeal of the instruction

The following section presents the results from the expert review in accordance to content and teaching information. The teacher had already read all of the web pages available in the 3D prototype before starting the evaluation so she knew exactly the content of the whole 3D prototype. The teacher started running the 3D prototype from the following URL: http://submission.intermedia.uib.no/~betzy/prototype/index.html

The teacher's answers are presented in quotation marks and her answers were translated into English. The questions are presented in italics.

- **Completeness:** The teacher was asked if the content about carbon chemistry topic was completely covered or if something was missing from the topic. She went through the main entrance of the 3D scene and entered the inorganic world where substances such as diamond, graphite, carbon dioxide and fullerene are shown and explained. She pointed out the following:

- *Is the content complete?*

"Yes, the content is complete, but its covers more than the textbook. The content in the 3D prototype is more extensive, especially the part that covers the inorganic substances and the new molecule fullerene"

Comments: The 3D prototype included a new substance inside the inorganic world that has recently being presented as an inorganic carbon molecule, which is fullerene (see Figure 41). The teacher indicated that this was too new and the textbook does not cover this new molecule at all.

Figure 41 Content completeness

Further she was asked whether she would like to add or change anything about the content:

-*Would you like to add or change anything about the content?*

" No, I like the way it was divided and I have not thought of anything that should be changed"

- **Accuracy:** The teacher continued going through the 3D world and reading the information displayed in the web pages. The teacher was asked if the content was accurate or if she thought that anything was unclear about the content.

-Is the content accurate?

"Yes, the content is accurate, but as I mentioned earlier, some of the molecules covered are beyond the curriculum, but this is fine. I particularly liked the table of contents with all the different molecules representations. It was well done with the colour codes"

-Is anything unclear about the content?

"The content is systematic, it is good. The content is a bit extensive, but it is an advantage because the students that want to learn more about this topic have the possibility"

Comments: The teacher went through all web pages paying particularly attention to the table of contents, especially the table that explained the different types of molecule representation (See Figure 42).

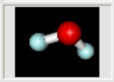
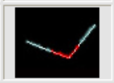
Modell	Formel	Fordeler	Ulemper
Kjemiskformel	H_2O	Viser hvor mange atomslag som finnes i molekylet	Viser ikke hvordan molekylet er bygd opp
Strukturformel	H-O-H	Viser hvor mange atomslag som finnes i molekylet og hvordan de er bundet til hverandre	Viser ikke hvordan molekylet virkelig ser ut
Kalottmodell		Viser avstanden mellom atomene i molekylet	Viser ikke atombindinger mellom atomene
Kule-pinnemodell		Viser bindinger i molekylet og hvordan atomer er plassert i forhold til hverandre.	Avstanden mellom atombindinger er for stor
Kapselmodell		Viser atomtype i molekylet og avstanden mellom bindinger	Viser ikke atombindinger mellom atomene
Trådmodell		Viser typer atomer i molekylet	Viser ikke atombindinger mellom atomene

Figure 42 Table of contents

- **Logical sequence:** This point tries to establish whether the sequence in which the 3D prototype presents information is logical or if something should be changed. While evaluating this point, the teacher went back and forward between the main hall and the three rooms of the 3D prototype. She pointed out the following:

  -Is the logical sequence of the content adequate?

  "Both yes and no"
  "Generally speaking, the whole 3D world has the right sequence when it comes to the subtopics, but there is a detail that should be changed when it comes to sequence. You should change the first information sign at the left hand side when ones entered the main hall. The cyclopentane sign should be moved to the right from the carbon atom film. And the sign about the carbon atom information should be placed at the left. That will be a more chronographical sequence for presenting information"

Comments: The signs to which the teacher is referring to are shown in Figure 43 with the changes she pointed out. The position of these signs was changed according to the teacher's specification: Sign A (Figure 43: A) changed position with sign B (Figure 43: B). The teacher meant that this was a more logical sequence for presenting first information about what is a carbon atom (Figure 43: A) and then showing the complex structure of the cyclopentane (Figure 43: B).

Figure 43 Logical sequence, changing signs position

The teacher continued the evaluation and went through the portal into the organic world. Here she pointed out the following:

> "Another thing that should be changed is in the organic world. Here, directions must be given about which sequence or order is more appropriate to follow. There is no indication of where to begin. It is fine to give an appropriate guidance that they should start looking at the alkanes first and then continue with other substances".

Comments: In the organic world, there was no sign or any indication with respect to where students should begin the exploration of this world. The teacher went through the portal and teleported the avatar to the organic world. She went inside the main hall but did not see any indication to where to start the exploration of this world. She pointed out this immediately and said that students could not know which topic to start reading first since they do not know the complexity of single, double and triple atomic bonding. She recommended to add some kind of guidance or information sign to this world indicating the appropriate sequence that students should follow in order to understand more complex topics. The organic world shows molecules of hydrocarbons with single, double and triple atomic bonding. Further, this world shows a more complex group called hydroxyls, which were already in a separate room.
The changes pointed out by the teacher were adjusted some days after the review. Figure 44 shows the main room of the organic world with two signs added. Sign A (Figure 44: A) shows an arrow indicating the direction in which students should start the exploration.

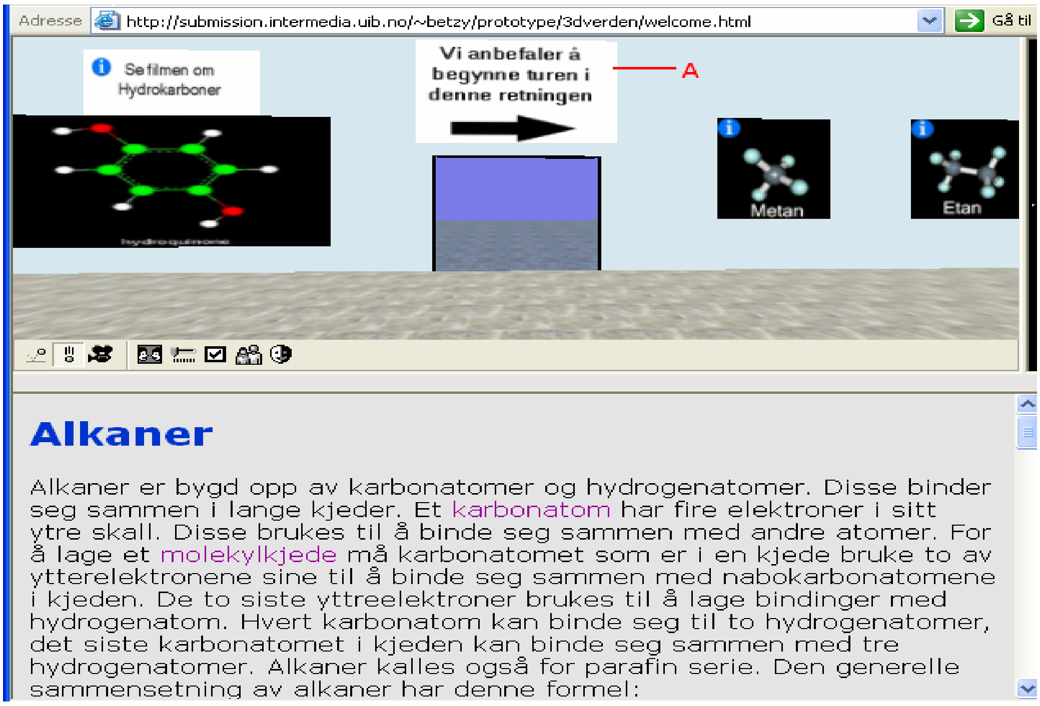


Figure 44 Logical sequence of the organic world

- **Narration level:** This point evaluates if the narration used to explain the content is suitable to the learners' level. Since the teacher had allready read all the web pages of the 3D prototype and, as she went through the 3D prototype during the expert review, she was asked if the langauge and the narration of the content was suitable for the students' level (10th graders are arround age 15). She pointed out the following:

  - Is the narration of the content suitable?

  " It is fine. Most of the web pages are built in such a way that the first sections start with easy stuff first and so the degree of difficulty increases. The language and narration used in the prototype is fine and is similar to the language used in the classroom and the books."

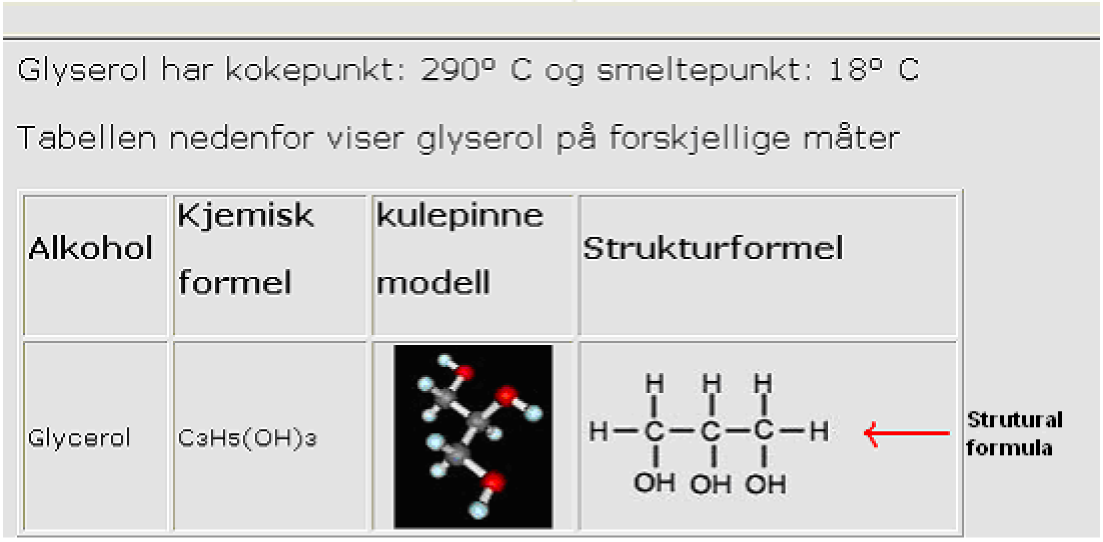
- **Match to learner's level:** this point evaluates if the content of the 3D prototype is adequate and match the students' level. The teacher was asked what she thought about the level of the content in the 3D prototype, she pointed out the following:

  - Is the level of the content adequate to learners level?

  " Yes, this is a topic for the 10th grade and it fits into the students' level, in spite of that some of the content in the prototype covered the topics a bit deeper than in the book"

Comments: What the teacher meant here is that some of the molecules shown in the 3D prototype are not covered in the textbook used by her class. As for instance, the molecule fullerene (see Figure 41) mentioned before. As she went through the organic world, she paid particularly attention to the table of contents about alkenes, alkynes and hydroxyls. These tables contain more information than students need to master.

Figure 45 shows an example of a table of content, which the teacher was referring to. The table shows structural formula, which is not required for students to know (Figure 45).



Glyserol har kokepunkt: 290º C og smeltepunkt: 18º C

Tabellen nedenfor viser glyserol på forskjellige måter

Alkohol	Kjemisk formel	kulepinne modell	Strukturformel
Glycerol	$C_3H_5(OH)_3$		H–C(H)(OH)–C(H)(OH)–C(H)(OH)–H

Figure 45 Tabel of contents of hydroxyl (Glyserol)

Another part of the 3D prototype that was important to evaluate, especially regarding the match to student's level, was the part about taking a quiz. In the 3D prototype, students can choose 4 quizzes that cover the topic of carbon chemistry. The teacher examined each of these quizzes carefully and pointed out the following:

> -*Are the tests difficult?*
>
> "The quizzes have a tolerable level for average students, but the weaker students can experience that they do not manage to answer some of the questions. What is good for weaker students is that they can help themselves by going inside the prototype and navigate in order to find the answers in the prototype while taking a quiz"
>
> "What should be changed here is the dialogue box, when one gets the answers. The questions should be provided too. In this way they can read the questions and answers simultaneously. You should show the questions in the dialogue box"

Comments: The 3D prototype includes 4 quizzes, when students answered all the questions from one sub-topic, a dialogue box is displayed showing the score and what option they answered. The dialogue box did not include the question text so it was not possible to remember what question was answered. Figure 46 shows the dialogue box with the question text included as suggested by the teacher.

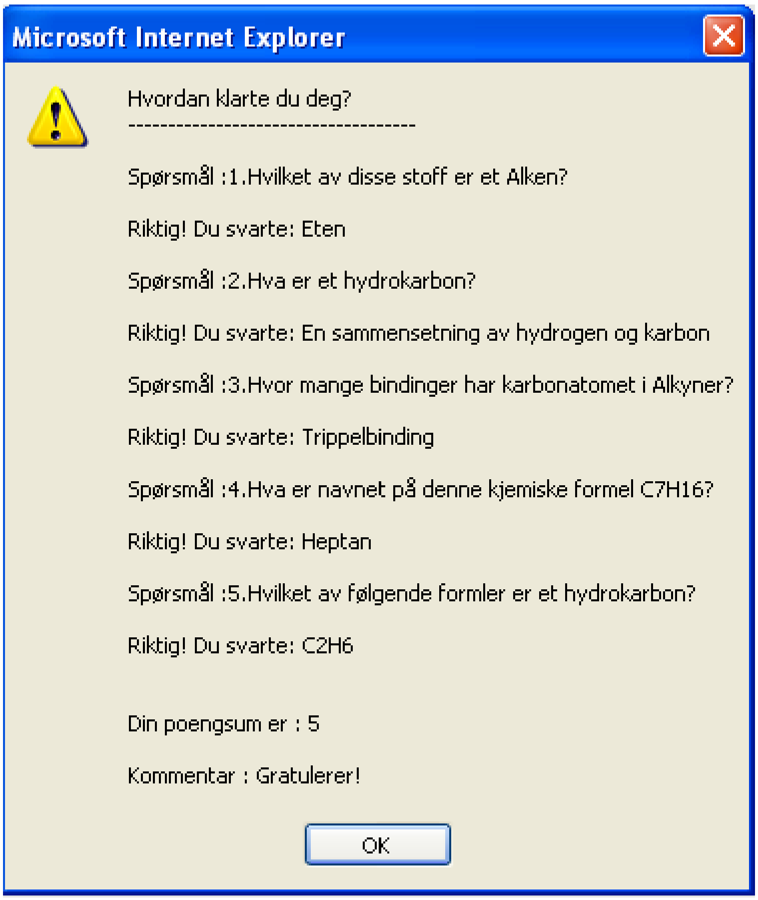


Figure 46 Dialogue box, showing the quiz's score

- **Curriculum fitness:** This point evaluates the level fitness; it concentrates more on the national curriculum for the 10th graders in general. The teacher was asked if the content fit into the curriculum. She pointed out the following:

  -Does the content fit into the curriculum?

  "Yes it does"

Further she was asked if her students would understand the content of the 3D prototype. She commented the following:

  - Would the students understand this content?

  " Both yes and no"
  It is not possible that it fits everyone. I think that images and the tables of contents will help the weaker students. The images (3D models) and the tables will help students that need to have visual aid in order to understand the topic. It is a motivation factor in itself that this is a computer program that presents the topic visually. Some of the students will find it difficult to understand everything, but the average students will understand most of the content in the prototype"

- **Appeal of the Instruction:** The last point considered for the expert review was about if the 3D prototype would be likely to be used by teachers. At this point, the teacher had finished using the 3D prototype and she answered some questions about appeal of the instruction: She was asked what she thought about the instruction (the 3D prototype) in general, to which she answered the following:

- What do you think about the instruction?

" I think it is a good combination of images and 3D objects; the visual aspect and the fact that one can navigate with avatars. It is very interactive to be able to manipulate molecules. One is very active and interacts a lot with the prototype in different ways, not only by clicking on links as in a web page".

Further she was asked if she would use this prototype as a part of her instruction. She commented the following.

- Would you use this prototype as a part of your instruction?

"Yes, I will. Carbon chemistry topic is very abstract and difficult to understand and one needs models in order to show the bonding between atoms. It is an advantage to have a facility that can be used to visualize and manipulate models that otherwise are difficult to understand"

Finally, some questions about the greatest weakness and the greatest strengths of the instruction were asked to the teacher. She commented the following about the weakness of the 3D prototype:

- Can you point out the greatest weakness of the instruction?

"I think the prototype could have more tests in every part or sub world. If this program is to be used to replace classroom teaching, it would be nice to assess the student's knowledge and what they learned. It is not easy to know what the students have learned"

The teacher also commented the following about the strengths of the instruction:

- Can you point out the greatest strengths of the instruction?

"It is a great advantage to visualise 3D models. In addition, the different types of interactions in the prototype are also good. To move around in the 3D world and the VRML browser by using the keyboard and the mouse keeps users concentrated on the task, because it is possible to interact with the prototype in different ways and this is motivating"

Before closing the expert review, the teacher was asked if there was anything she would like to change in the 3D prototype. She answered the following:

- Is there anything you would like to change?

" Yes, I would like the prototype to have more in it, while navigating in the 3D world. Apart from that, nothing else"

The following section presents the results from the one-to-one evaluations.

12.2 One-to-One Evaluations/Usability Test

One-to-one evaluation involves a review of the interface with one subject and one evaluator. The evaluator sits with the user and observes the subject while using the program. The evaluator takes notes under the reviewing and at the end the user is interviewed.

Goals of One-to-One Evaluation: The main goal of this stage of formative evaluation was to discover usability problems such as: ease of use, user control and freedom, consistency and standards, feedback, navigability and system help. For this purpose, a usability test was carried out in the following way:

Preparing the Evaluation: Before starting the evaluation, subjects were informed about the purpose of the evaluation. They were told that it was the system that was being evaluated not them. They were informed of the purpose of the evaluation, and how long the evaluation would take. The subjects were also informed about the procedures of the evaluation and that they were going to be observed while using the 3D prototype and that notes would be taken. Further they were informed that after finishing the reviewing of the 3D prototype, an interview was to take place and that the interviews were going to be disc-recorded, which they agreed to. Subjects were also told to ask questions under the evaluation if needed. Subjects were first given a questionnaire to fill in before starting to use the 3D prototype. Then they were given a set of pre-defined tasks to be performed by using the 3D prototype. They read the set of tasks and were told to ask questions if something was unclear. Then subjects started using the 3D prototype. Observation took place; notes were taken and some questions were answered during the evaluation when subjects asked for help. Finally when the subjects finished the predefined set of tasks, a break of 15 minutes took place before starting the interviews. The interviews were disc-recorded with a Mini Disc.

The evaluation of the 3D prototype was performed with one subject at the time and it took several days to perform. Table 24 shows an overview of the evaluation activities, and the subjects involved in the evaluation.

Evaluation date	**Persons involved**	**Activity**
13.02.2004	Two students from Ytrebygda school	One-to-one evaluation/usability test
23.02.2004	Teacher Brit Aarstad	One-to-one evaluation/usability test
08.03.2004	Teacher Kirsten Knudtzon	One-to-one evaluation/usability test
11.03.2004	Teacher Idar Mestad	One-to-one evaluation/usability test
12.03.2004	Teacher Anne Aasdal	One-to-one evaluation/usability test

Table 24 Evaluation activities

The next section presents the results from the usability test. Data gathering was performed with three methods: questionnaires, observation and interviews. First the results from the questionnaires are presented, followed by the results from the observations. Finally the results from the interviews are presented.

12.2.1 Questionnaires Results

Before starting to use the 3D prototype, subjects were given a questionnaire. The information sought from the questionnaires was about the subject's profile and computer use.

The following types of questions were used:

- **General questions**: Subjects were asked questions about age, sex and occupation

- **Multi-choice**: Subjects were presented with a choice of explicit responses and were asked to select yes or no. The questions of this section concerned: access to pc at home, access to the Internet, and use of 3D programs

- **Ranked**: A list of different applications was presented and subjects were asked to rank the items of the list according to how often they were used. The questions of this sections concerned: use patterns of pc, Internet, 3D games and web-based learning programs

The questionnaire given to subjects can be seen in Appendix C

The following section presents the results from the questionnaires, the observations and the interviews separately.

The data gathered from the questionnaires is presented in tables 25, 26 and 27.

Personal information: Subjects were asked questions about age, sex and occupation:

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
Age	15	16	35	30	35	30
Sex	Female	Male	Female	Female	Male	Female
Occupation	Student 10th grade	Student 10th grade	Middle school teacher	Middle school teacher	Middle school teacher	Middle school teacher

Table 25 The subjects, personal data

The two students, **S1** and **S2** are the same students that participated under design phase. They are above average learners and have all the preliminary knowledge necessary to understand the topic of carbon chemistry. They also had previous knowledge of 3D programs, as they were shown some of the applications available on the Web. These two students and the teacher, Helga Sunde, were asked if they would like to partitipate in the evaluation of the 3D prototype which they agreed to.

Subjects **S3 and S5** are middle school teachers from Knarvik middle school in Bergen and have taught the 10th grade level before. All of the teachers were contacted by mail
S4 and **S6** are middle school teachers from Nygårsskolen in Bergen and have taught different levels from 2nd grade to 10th grade. All of the teachers were fully qualified to participate in a

usability test of the 3D prototype. All of the teachers agreed to participate and the date for the evaluation was set according to their available time (see Appendix D).

Access to pc and the Internet
The subjects were asked to answer yes or no to the following questions:

	S1	S2	S3	S4	S5	S6
Access to pc at home	yes	yes	yes	yes	yes	yes
Access to Internet at home	yes	yes	yes	yes	yes	yes
Access to Internet other places	yes	yes	yes	no	yes	yes
Used of 3D programs before	no	no	no	no	yes	no

Table 26 PC access

All subjects **S1-S6** had access to a personal computer at home as well as access to the Internet at home, which made them all equal when it comes to pc and Internet accessibility. All subjects except for **S4** had access to the Internet at other places. **S1** and **S2** specified that they had access to the Internet at school. Subjects **S3, S5** and **S6** had also access to the Internet at work, which are the schools they work for. **S4** did have access to Internet at work but did not use it.
Concerning the use of 3D programs, all subjects, except for **S5** had never used a 3D program before. **S5** had used 3D programs before, called Molekyl.

PC and Programs' Patterns of Use
Subjects were asked to range how often they used computers and how often they used certain programs as shown in Table 27.

	S1	S2	S3	S4	S5	S6
Daily use of pc	0-1 hour	0-1 hour	2-3 hours	0-1 hour	2-3 hours	0-1 hour
Use of the Internet	Weekly	Daily	Daily	Daily	Daily	Weekly
3D games	Seldom	Weekly	Never	Never	Weekly	Never
Chat programs	Weekly	Daily	Never	Never	Seldom	Never
Web-based learning programs	Seldom	Seldom	Never	Never	Monthly	Never

Table 27 Programs pattern of use

Four of six subjects (**S1, S2, S4** and **S6**) used personal computers 0-1 hour a day, while two of six subjects (**S3** and **S5**) used personal computers 2 to 3 hours a day. When it comes to use of the Internet, four of six subjects (**S2, S3, S4** and **S5**) used the Internet on daily basis, but two of six subjects (**S1** and **S6**) used the Internet on a weekly basis.
Subjects were asked about how often they used certain programs such as 3D games, for instance, two of six subjects (**S2** and **S5**) used 3D games on a weekly basis, it is worth noting that both **S2** and **S5** are males, while three of six subjects (**S3, S4** and **S6**) had never used 3D games before. One of six subjects (**S1**) had used 3D games seldomly.
When it comes to chat programs, three of six subjects (**S3, S4** and **S6**) had never used a chat program at all, while **S1** used it on a weekly basis. **S2** used chat programs on daily basis and **S5** used it seldom. Finally, subjects were asked how often they used web-base learning

programs. Three of six subjects (**S3, S4** and **S6**) had never used a web-based learning program before. Two of six subjects (**S1** and **S2**) had used web-base learning programs seldomly and only at school. **S5** was the only subject that used web-based learning programs monthly and this subject used web-based learning programs at work, at the middle schools he teaches.

12.2.2 Observation Results

During the one-to-one evaluations, the students and teachers who participated in the evaluation were first given a set of pre-specified tasks to be accomplished within 1 hour.
The tasks were designed to cover the most important parts of the interface and were as representative as possible of the intended use of the 3D prototype. While performing the task, the subjects were observed and notes of the subjects' interactions with the 3D prototype were taken.

The following section presents a summary of the observations made under the evaluation.
Only the most relevant observations are presented, which are the tasks where the subjects experienced difficulties using the 3D prototype.

The subjects were given the tasks listed in Table 28 (To see the original text in Norwegian, refer to Appendix E).

Task instructions
0 Start the 3D prototype go to http://submission.intermedia.uib.no/~betzy/prototype/index.html 1. Chose and avatar and begin to navigate in the 3D scene 2. Try the different buttons under the 3D scene, what happens then? 3. Enter the main building and look around, read the information sign 4. Choose one molecule and try to manipulate the molecule that pops up at the right frame by using the buttons in the VRML browser 5. Read the information displayed in the web page 6. Use the links and try to navigate back and forwards between pages 7. Print one page 8. Go through the portal into the Organic world 9. Go inside the main hall and look around 10. Choose one molecule and test the change style button in the VRML browser, what happens? 11. Go inside all the rooms in the organic world and go back to the main world 12. Go to the right room, the synthetic world and click on the guest book 13. Post a comment in the guest book 14. Test the menu and the go! button in the navigation frame 15. Choose a topic and read the information 16. Use the quiz button, choose a quiz and answer it 17. Try the home button in the navigation frame 18. Exit the prototype

Table 28 Task instructions

The results from the observations are presented task by task and subject by subject, followed by comments and illustrations of the task and problems they encountered. The comments that subjects came up with during the evaluation are presented in italics and quotation marks.

Task 1: Choosing and Avatar and Entering the 3D Scene

S2: This subject had no difficulties performing this task.

S1: Chose an avatar from the list of available avatars but needed help to know how to change the avatar. Needed help to know how to activate the 3D scene window. The subject did not know where to click on the 3D window in order to start navigation in the 3D world

S3: Chose an avatar, but needed help to know how to change the avatar. The subject had difficulties when entering the 3D scene. Subject was told to click on the 3D scene in order to activate it and start navigation.

S4: Had some difficulties when choosing the avatar, she asked:
"What is an avatar?" The subject was told how to choose an avatar. Subject switched on and off the show my avatar button. Subject needed help to know how to activate the 3D scene window.

S5: Subject started the program and read very carefully the first information page that appears. He commented*: " Most of the students will not know what VRML and Avatar means"*
He started testing the buttons under the 3D scene, He chose an avatar, switched on and off the show my avatar button.
The subject had difficulties when using the 3D scene. He needed help to know that in order to activate the 3D scene one has to click on the window. Subject clicked on all the buttons to see if something happened in the 3D world. He commented: " *It is not good that one has to click on the 3D scene in order to active it".*

S6: The subject started the program and read the first information page. She commented:
"I do not know what VRML browser or Avatar is?". Subject chose one avatar.
She used the help button and read all the information carefully and got information about how to activate the 3D scene. This subject had no difficulties performing this task.

Comments: The difficulties that some of the subjects had when choosing and avatar and entering the 3D scene can be summarized as follow:
Three of six subjects (**S1, S3** and **S4**) had difficulties using the controls for choosing an avatar. Figure 47 shows the task in question: To choose an avatar, users must click the avatar button (Figure 47: A). Then a window with available avatars appears. To choose or change an avatar, users need to click on the avatar and drag it into the Current Avatar window as shown in (Figure 47: B).
Another difficulty performing this task was entering the 3D scene. Users had to click inside the 3D scene in order to activate it as shown in (Figure 47: C).

Figure 47 **Choosing avatars**

Further, four of six subjects **(S1, S3, S4, S5)** needed help to know how to activate the 3D scene. These subjects were told that they had to click on the 3D scene window in order to activate it and start navigation (see Figure 47: C). Only subject **S2** and **S6** entered the 3D scene without needing help.

Task 2: Testing the Buttons under the 3D Scene Window

Figure 48 shows task 2: Subjects were asked to test all of the buttons under the 3D scene window. The functions of these buttons are explained in Table 17.

Figure 48 **Testing the 3D scene buttons**

S1 and S2: Tested the chat function and other buttons without difficulties. **S2** is presented because he came up with some comments while performing the task.

S2: Subject started testing all of the buttons under the 3D scene. He tested collide, gravity, show my avatar and got the avatar to fly. The subject tried to use some shortcuts like A,W, S, D, in order to move the avatar in a more advance way but he realised that these shortcuts were not available in the 3D prototype. The subject was interrupted and was asked what he was doing and he answered:
" I am trying to move the avatar in a more advanced mode like strafing instead of rotating which is something I am used to when playing Half-life 3D game"

The subject continued using the 3D prototype and was now testing the chat function. He tried a shortcut (/nick) in the chat window in order to give a name to the avatar. He chose the shortcut, instead of using the preference button, which displays a dialogue box, where users can enter the name of their avatars.

S3: Subject entered the 3D world and started using the buttons under the 3D scene window.
Subject started testing the chat function, and needed help to know how to write a message in the chat window. Subjects did not know where to click in order to activate the chat window.
She tested the preference button, gave a name to the avatar. Tried the controls button and tested all of the functions for the avatar, like making the avatar invisible, visible, shorter, larger. She tested collide and gravity buttons and try to make the avatar fly. She also tested the show my avatar buttons on and off.

S4: Subject tested the chat function but did not know how to activate the chat window and write a message. The subject was shown where in the chat window to click in order to write a message. Subject tested the controls button and tried all the functions available for the avatar, like opaque, disappear etc. Subject used the help button but only read the first page, instead this subject started to try on her own. Subject tested the preference button and gave the avatar a name.

S5: He tried the chat function but had difficulties using it. He did not know where to click in the chat window in order to write a message. He started clicking everywhere in the chat window without succeeding. It was necessary to show him where to activate this chat window.
Subject tried the controls button and moved the avatar, he tried to make the avatar lager, shorter, invisible, etc. He tried the gravity and collide buttons

S6: Subject explored all of the buttons under the 3D world. She tested the preference button and gave a name to the avatar. The subject tried the chat function but had difficulties in writing a message. She started clicking everywhere on the chat window without managing to activate the window in order to write a message. Finally, the subject had to be shown where to click.
She tried the controls buttons and tested all the available movement for the avatar.
She tested the show my avatar button and the gravity button.

Comments: The difficulties when performing task 2 can be summarized as follows:
Four of six subjects **(S3, S4, S5, S6)** had difficulties when using the chat function. They did not know how to activate the chat window in order to write a message. Figure 49 shows the problem with this task. Users had difficulties knowing where to write a message in the chat window and had to be shown which area to click in order to write a message as shown below:

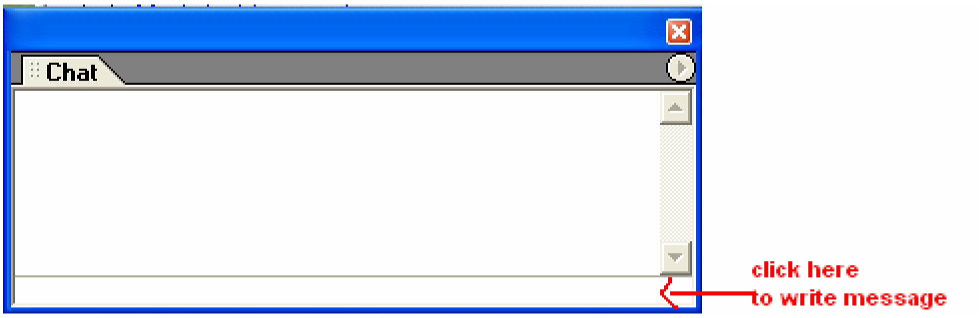


Figure 49 **Difficulties using the chat window**

Task 3: Entering the Main Hall in the 3D Scene

Figure 50 shows the information sign (Figure 50: A) that subjects were asked to read when entering the main hall

Figure 50 **The main hall and the information sign**

S2, S3, S4, S5: These subjects had no difficulties performing this task.

S1: Subject entered the 3D scene; the main hall and read the information sign, but had some difficulties when reading the sign because the avatar was obstructing the sign. Subject tried to move the avatar aside so she could read the information sign. The subject followed the instructions given in the sign.

S6: The subject entered the main building and read the information sign and followed the instructions given there. She had problems reading the sign because the avatar was in the way.

Comments: Two of six subjects (**S1, S6**) had difficulties reading the sign because the avatar was obstructing their vision. The other subjects moved the avatar or made it invisible or transparent so they could read the information sign without difficulties.

Task 4: Testing the VRML Browser

Figure 51 shows task 4: subjects were asked to choose one molecule (Figure 51:A) and try all the buttons in the VRML browser (Figure 51:B).

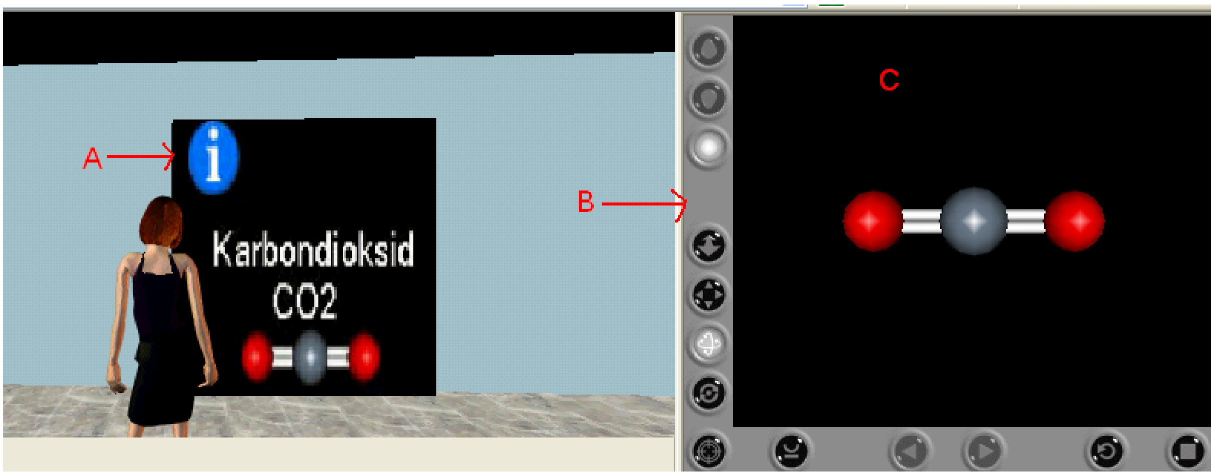


Figure 51 Testing the VRML browser

S2: This subject has no difficulties performing this task.

S1: Subject entered the inorganic world first; chose a molecule and started using the VRML browser. This subject had difficulties while using the VRML browser and the buttons on it. The subject clicked on the buttons and said: *"Nothing happens when I press these buttons"*. After some trials, she realised that after selecting a button, the mouse must be used in order to move the molecule in the VRML browser window.

S3: Subject entered the inorganic room and chose one molecule. She tried to manipulate the molecule in the VRML browser but asked for help. Subject had problems to understand how the buttons worked. The subject clicked the buttons but did not use the mouse or keyboard in order to move the molecule. Subject started using the mouse to move the molecule, then commented: *"some of the buttons in the VRML browser do not function at all"*.

S4: Subject entered the inorganic world and chose a molecule, started using the VRML browser and commented: *"The VRML browser is quite confusing"*
She started to use all the buttons in the VRML browser and pointed out that the buttons had an understandable image on it. The subject had difficulties using the buttons; she clicked on the buttons but did not use the mouse to manipulate the object and commented:
"Nothing happens when I click on the buttons"

The subject had to be told that after choosing one button one has to click on the molecule and move the molecule by using the mouse or the keyboard.

S5: He chose one molecule and started using the VRML browser. Subject had difficulties when using this browser. He clicked on the buttons and commented: *"nothing happens"*.
Then subject was shown that after choosing one button, one has to click on the molecule and move the mouse pointer in order to move the molecule. He tested all the buttons and used also the keyboard arrow up and down.

S6: She chose one molecule and started using the VRML browser. The subject had difficulties when using the VRML browser; she started clicking all the buttons and commented:

“ *Nothing is happening here?*” The subject was shown how the buttons of the VRML browser functioned. She noticed that some of the buttons were disabled.

Comments: Five of six subjects **(S1, S3, S4, S5, S6)** had difficulties when using the VRML browser. The problem arose when using the buttons of the VRML browser (see Figure 51: B). The subjects clicked on the buttons and waited for some feedback, but when they did not receive any, they had to be told that in order to move the object in the VRML browser window, one has to click on the window (see Figure 51: C) and move the mouse or use the arrow keys in the keyboard in order to manipulate the object.

Task 5, 6 and 7: Testing web pages and links
For performing these tasks subjects were asked to read information in the web pages, to use the links and try to navigate back and forwards between the pages and print one page.

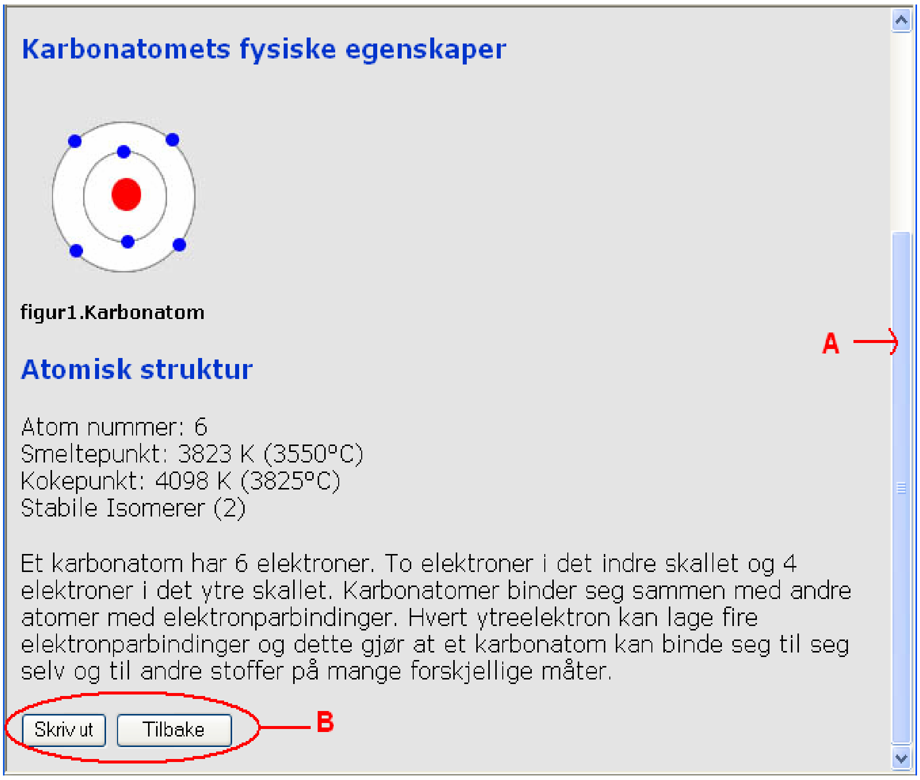


Figure 52 Testing web pages

S3, S4, S5, S6 : These subjects had no difficulties performing this task.

S1: The subject read the information page shown in the information frame and used scrolling to read all of the text. She tested the print button for printing a page. She read web pages of this section but did not manage to navigate back and forward between the pages. She did not see the back buttons located at the bottom of the web pages.

S2: The subject read the web pages shown in the information frame and used scrolling for reading the text. He did not use the buttons at the bottom of the pages.

Comments: Two of six subjects (**S1, S2**) did not see or use the buttons for printing and navigating between pages (see Figure 52: B). All subjects used scrolling (see Figure 52: A) in order to read the whole text in the web pages.

Task 8 and 9: Testing the Portal and the Organic World

Figure 53 shows tasks 8, entering the portal into the organic world.

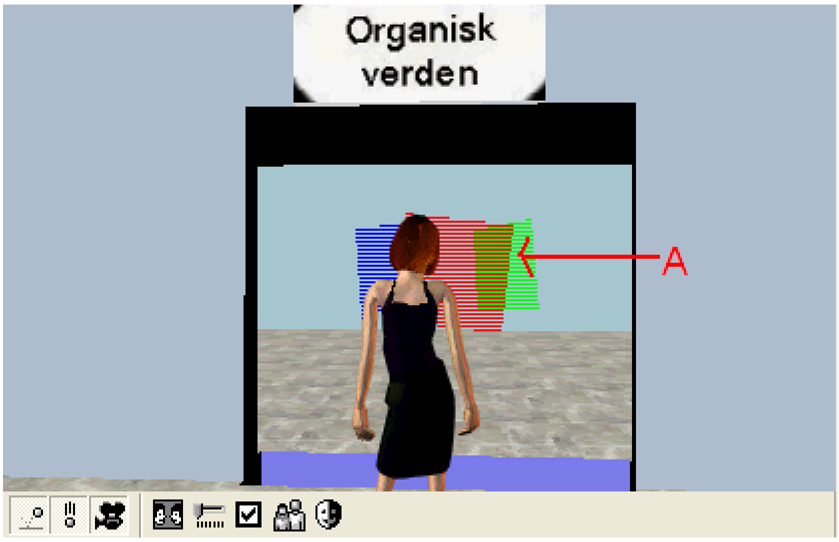


Figure 53 Entering the portal into the organic world

S1, S2, S3, S5, S6: These subjects had no difficulties performing this task.

S4: Subject entered the portal but had difficulties in understanding what was happening, she tried to move the avatar with the arrow keys while inside the portal and commented: "*the avatar is not moving*". Once in the organic world, she went inside the building and read the information sign. She chose the sequence suggested in the sign.

Comments: One of six subjects (**S4**) had difficulties using the portal. This subject tried to move the avatar while it was teleporting to the organic world. The avatar cannot move while inside the portal (see Figure 53: A). Users have to wait until the avatar arrives to the other 3D world location.

Task 10: Testing the Change Style Button

Figure 54 shows task 10. Subjects were asked to choose one molecule and test the change style button (Figure 54: A) in the VRML browser.

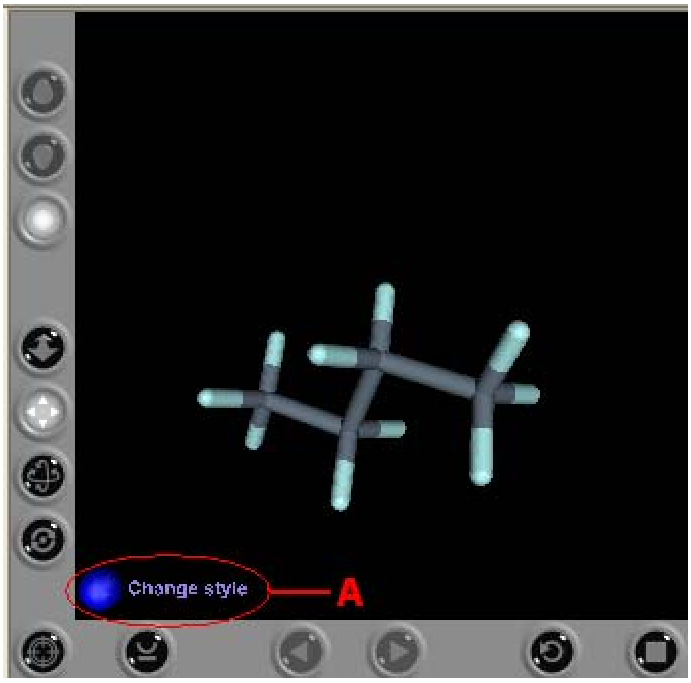


Figure 54 Testing the Change style button

S1, S2, S3, S4, S5: These subject had no problem performing this task.

S6: She chose one molecule and tried to use the change style button. She had some difficulties when using this button; the subject clicked on the word **Change style** instead of clicking on the blue button. Subject commented: *"I don't see anything happening here"*

Comments: One of six subjects (**S6**) had difficulties when using the change style button as shown in (Figure 54: A). The subject tried to click on the word and not on the blue button leading to getting no feedback at all.

Task 11: Exploring the Organic World and Returning to the Main World

S3, S4, S6: Had no difficulties performing this task.

S1: The subject tried to interact with a book that lies on a table in the main hall, and commented: *"Nothing happens here"*. But this book had no form for interaction. It was there for decoration reasons only.

S2: The subject moved around in the main hall and started clicking on all objects in the organic world, especially the book on the table and commented:
"I don't get any response from the book, what's happening?"

S5: Subject continued the exploration towards the hydroxyl room. Here he found an error in one of the pages. He pointed out that one of the molecules about the organic solvents lacked one code colour explanation (the light blue colour for hydrogen's atoms)
Subject went back to main world and tried to interact with the books in the main room, he tried to click on them and went to another room.

Comments: A difficulty when performing this task was that three of six subjects (**S1, S2**, **S5**) tried to interact with the book placed on the table in the main hall (see Figure 55:A). These books were only for decoration reasons and do not provide any kind of feedback.

Figure 55 **Interacting with objects**

Task 12 and 13: Testing the Guest Book
Subjects were asked to go to the synthetic room and click on the guest book as shown in Figure 56:

Figure 56 Testing the guest book

S2, S5, S6: These subjects had no problem performing the task. However, S5 and S6 had another kind of problem that is more related to Internet Explorer browser than to the 3D prototype.

S1: Subject went back to the main world and visited the synthetic room. She interacted with the guest book but had problems with the post button. The subject needed help to understand how to post a comment into the guest book.

S3: Subject went back to the main world and into the synthetic room where she tested the guest book. She did not know how to post a comment into the guest book and needed some help.

S4: Subject went back to the main world and entered the synthetic world. There she chose the guest book and started writing a comment. She had difficulties when posting the comment and did not know which button to use. She also got an error message because she had not filled in the obligatory e-mail address field.

S5: The subject entered the synthetic room and chose one molecule.
Then he clicked on the guest book and the browser Internet Explorer crashed at this point.
The subject restarted the program and went directly to the guest book, writes a comment and posted it without difficulties.

S6: In the main world, the subject entered the synthetic room and clicked on the guest book. The web browser Internet Explorer crashed and the program had to be restarted.
The subject restarted the program and went directly to the synthetic room and clicked on the guest book again, and wrote a comment. She had difficulties knowing what kind of function the show button had, but had no problem when posting her comments.

Comments: Three of six subjects (**S1, S3, S4**) had difficulties posting a comment into the guest book. The difficulty arose after they finished writing their comments. Subjects did not know how to post it. Figure 57: A shows this point:

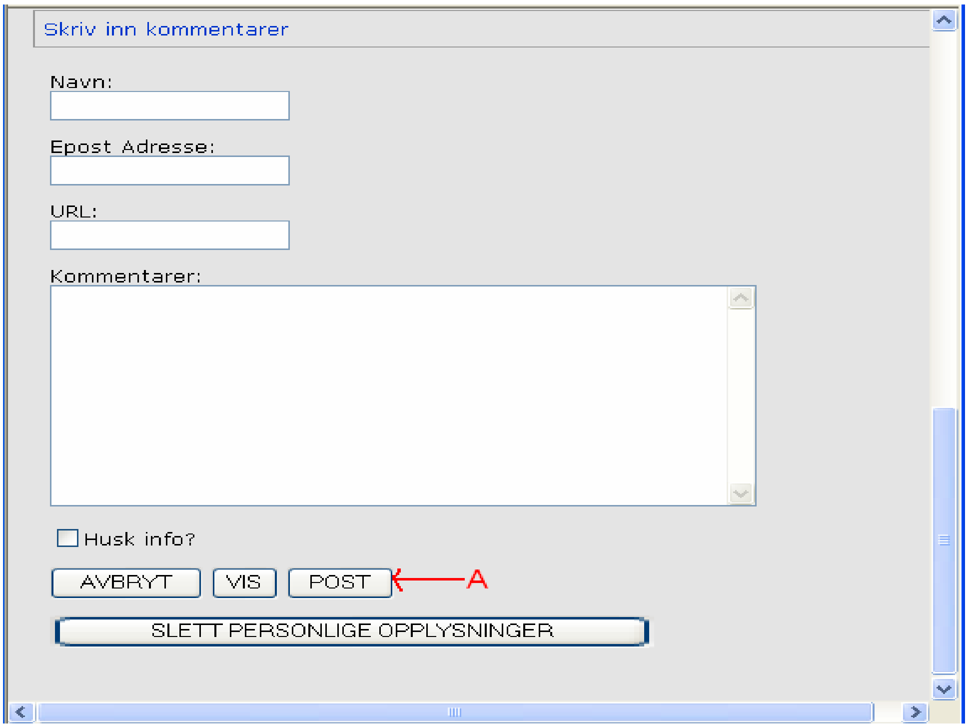


Figure 57 Posting a comment into the guest book

Another problem that arose while performing this task was that two of six subjects (**S5** and **S6**) crashed Internet Explorer when they clicked on the guest book. They had to restart the web browser Internet Explorer and started the program again. The important poin is that Internet Explorer crashed at exactly the same point.

Task 14 and 15: Testing the Drop Down Menu and "Go" Button
Figure (58:A) shows the drop down menu and the *go* button being tested:

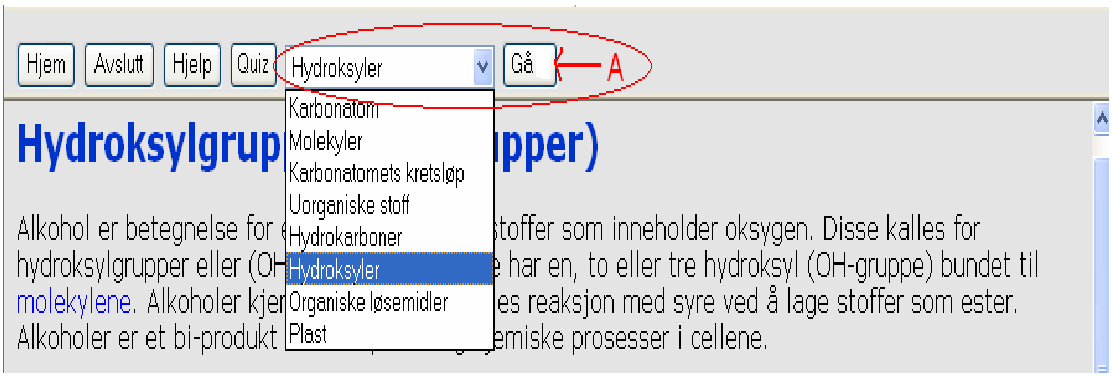


Figure 58 Testing the drop down menu

S1, S2, S3, S4: The subjects tested the drop down menu and the *go* button placed at the navigation bar without any difficulties.

S5: He tried the *go* button but had difficulties using it. Did not understand that the drop down menu and the *go* button functioned together. He clicked on the go button without choosing an option from the menu, then nothing happened
He commented: " *here it is better to use go to! or show! instead of go!"*

S6: The subject tested the go button but had difficulties using it. She clicked on the button while first choosing an option in the menu beside the button.

Comments: Two of six subjects (**S5, S6**) had difficulties understanding the function of the drop down menu and the *go* button. These subjects did not understood that the menu and the *go* button function together. First one chooses the topic in the drop down menu and then one click on the *go* button. The text label of the *go* button was changed to *go to* (Norwegian: gå til!) after getting this feedback for subjects **S5** and **S6**.

Task 16: Taking a Quiz
Figure 59 shows the task being performed: Subjects were asked to test the quiz button (Figure 59:A), to choose one quiz (Figure 59:B) and to answer it (Figure 59:C)

Figure 59 Taking a quiz

S1 and S2: Subject chose the quiz button and took a quiz without difficulties.

S3: Subject took the quiz and pointed out that the dialogue box did not provide information about what was being answered.

S4: She took a quiz and read carefully the dialogue box that popped up showing the scores. She commented*: "There is no information about what I answered"*

S5: He took a quiz and commented: "*I think some of the questions may be too difficult for the students"*

S6: The subject took a quiz and read the dialogue box carefully and commented: *" I can not see what I answered, I not sure people will remember their answers"*

Comments: Four of six subjects **(S3, S4, S5, S6)** commented that the dialogue box that shows the score from the quiz do not include any information about what was answered when their answer was wrong, but only included the right answers see (Figure 60:A)

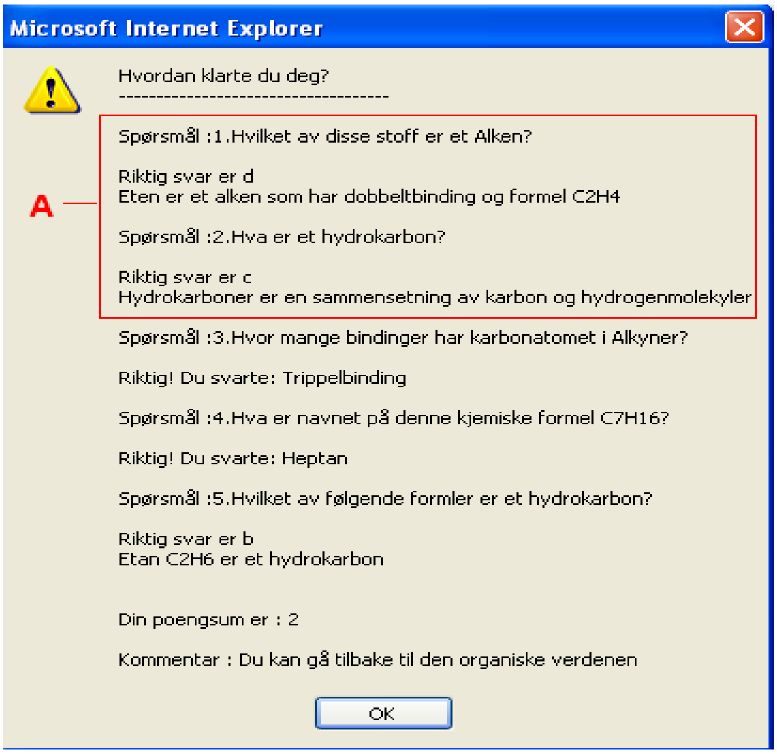


Figure 60 **Feedback from the quiz dialogue box**

Task 17 and 18: Testing Navigation Bar Buttons and Exiting the 3D Prototype

Figure 61 shows task 17 and 18: Subjects were asked to test the home button and to exit the 3D prototype.

Figure 61 **Exiting the prorotype**

S1, S2, S3, S4, S5, and S6: The subject tested the home button and the exit button as shown in (Figure 61:A) ending thus the evaluation.

The following section presents the results from the interviews session after subjects finished using the 3D prototype.

12.2.3 Interview Results

The subjects were interviewed right after they finished the set of tasks. One of the major advantages of performing the interviews after they finished using the 3D prototype was that they remembered what they had done and could reflect upon their interactions with the 3D prototype. The questions asked under the interviews were designed in advance taking into account the 7 heuristics principles listed in Table 29 (for a detailed explanation of heuristic principles see Table 22).

• Speak the users' language
• Minimize the users' memory load
• Consistency
• Feedback
• Clearly marked exits/user control
• Shortcuts
• Help and documentation

Table 29 Heuristics principles used for the evaluation

Interview Guide Description

This section presents how the questions for the interview were designed, taking into account the heuristic principles listed in Table 29. Each principle generated a set of questions as explained below. To see the interview guide refer to Appendix F for the interview guide in English. To see the interview guide questions in Norwegian, refer to Appendix G.

Speak the user's language: As mentioned in Table 20, this heuristic principle is about trying to match the system with the real world, which means keeping the language as familiar to the target users as possible and avoid foreign and technical terms when possible. Subjects were asked about the language used in the 3D prototype. For instance, if the language was too technical or if the terminology used throughout the web pages and inside the 3D scene was easy or difficult to understand.
Another important point of this heuristic principle is to match the system metaphors with the real world. Subjects were asked if they understood the metaphors used in the 3D prototype, for example, the house/building metaphors implemented in the 3D scene. Subjects were asked what they thought the building and rooms try to illustrate and what kind of functions each room in the 3D scene have, as well as whether it was difficult or easy to understand the function of the signs inside the 3D scene.

Minimize the users' memory load: This heuristic principle is about keeping information available and visible whenever needed in the system. Subjects were asked if dialogue boxes and information remain on the screen whenever needed. Another question was around the dialogue boxes in the 3D prototype, especially the dialogue box that appears when taking the quiz, they were asked what they thought about that dialogue box and the messages displayed on it.

Consistency: This principle is about standards that the system is to be built upon, in other words, whether users' actions or command can be interpreted the same way throughout the system. Subjects were asked if they could repeat the same action in other parts of the 3D prototype and get the same feedback or results. They were also asked if information was formatted the same way and whether buttons were placed in the same location in every web page and if they have the same look. Another question that touches consistency principle was about the colour codes used in the 3D prototype in general, fonts, links, background colour, etc.

Feedback: The main point of this heuristic principle is to keep the users informed of what is going on with the system. Subjects were asked if the 3D prototype, 3D scene, VRML browser and the web pages gave feedback to them when interacting with it. They were also asked whether the response time of the 3D prototype was quick or slow after an interaction.

Clearly marked exits/user control and freedom: The 3D prototype intends to provide mechanisms for exiting and undo actions whenever the user wishes to. Subjects were asked whether it was possible to exit the 3D prototype at any time and at whatever location. Another question related to this heuristic principle was if they could repeat an action or end it if wanted and if the prototype's controls could be switched on an off at will. When it comes to navigation possibilities, subjects were asked whether it was difficult or easy to navigate in the 3D scene, the VRML browser and the web pages and to specify their answers with examples. Another related question was about the frames of the 3D prototype and whether it was difficult or easy to know which frame to focus on when interacting with the 3D prototype.

Shortcuts: This principle points out that users should have the opportunity to interact with the system in a quicker way if wanted to by creating functions that make this possible. In order to get information from subjects about this point, they were asked if it was possible to jump to a desired location of the 3D prototype, whether a web page or a 3D scene without having to go through the whole system. Subjects were asked what they thought about the function of the go to button with a drop down menu.

Help and Documentation: This principle points out that any system should provide documentation, help and search possibilities in order to help users with tasks to be performed on the system. The 3D prototype has a help button and subjects were asked if they used this function at all, and if they found the information they were looking for or whether they missed any other type of help function in the 3D prototype.

At the end of the interviews, subjects were asked two open questions. One question is about interaction; if they missed any other form of interaction with the 3D prototype and to comment on the interaction options available in the 3D prototype.
The other question was about appeal, acceptance and motivation. Here subjects were asked if they would like to use the 3D prototype for learning more about the carbon chemistry topic and if the 3D prototype can be a motivation factor to learn about the carbon chemistry topic. Finally subjects were asked a question of appeal and acceptance, whether they think the visual aspect of the 3D prototype will help to use it.

The following section presents the results from the interview; the usability problems found during the interview will be presented pointing to the heuristic principle breaches. Subject's answers are presented in quotation marks. Only the subjects' answers that reported a usability problem will be discussed in this section. Subject's answers that did not point to a usability problem are not included in this thesis, since there is no point in presenting positive answers when looking for usability problems.

12.3 **Usability Problems**

This section presents the usability problems reported by subjects in the interview sessions after they completed evaluating the 3D prototype. The usability problems will be presented linked to the breaches of the heuristic principles. Each usability problem will be labelled with the letter **U** and a number. For instance, **U1, U2**…and so on in this order. For each usability problem reported, the subjects who reported it are quoted and are labelled **S1, S2, S3, S4, S5** and **S6**. The questions asked are presented in italics

Heuristic 1: Speak the Users' Language

Four breaches were reported for this heuristic principle. The breaches were about language being too technical, or using foreign terms instead of native language, terms being too difficult to understand, the interface metaphor being unclear and information signs being difficult to read.

U1: Language too Technical or Foreign

Three of six subjects (**S2, S4, S5)** pointed out that terms used in the information pages of the 3D prototype were too technical and difficult to understand and some of the terms were explained in foreign language (English)

- *Is the language used in the program too technical?*

> **S2:** "No if you read the help pages it is easy to understand, but if one does not read them and only use the prototype, one may wonder what VRML browser means" It can be difficult to understand".
>
> **S4:** " I think the language used in the help pages is too technical, I know a lot about computers, but when one reads terms that you never heard of before you get stuck with that term, such as avatar and VRML browser. For instance, in the help pages where you use VRML browser, one can used the frame to the right instead, because everybody understand this term"
> "…For instance a Norwegian text saying (rotere) rotate or (vri) turn, something like that, but not using English terms"
>
> **S5**: "Yes it was too technical. For instance words like avatar and VRML. I don't think students know what avatar and VRML means. I would have used, the frame to the right instead of VRML; and the term animation or figure, instead of avatar"

U2: Difficult Terms

Another usability problem when it comes to language was found in some of the terms used in the web pages, for instance, subjects (**S1, S5)** pointed out that some of the terms used in the web pages to explain the topic of carbon chemistry were difficult to understand.

-Is the terminology used in the program easy or difficult to understand?

> **S1**: "You know what. The terms were a little bit difficult, but I did not try to concentrate in the content so much. I was more focused on using the prototype"
>
> **S5**: "The terms cover more than the curriculum, I think there are too many terms, but this is the way the carbon chemistry topic is. Students are introduced with many new terms. I think the web pages have too much text. You could have less text and more links"

U3: Interface Metaphor Unclear
Subjects were asked what they thought the 3D scene and the rooms inside the main building represented. Five of six subjects answered the same, that the 3D prototype, the building and the rooms represented the three major sub-topics of carbon chemistry topic. Only one subject had difficulties in understanding the metaphor.

- *What do you think the 3D scene represents?*

> **S2:** "Nothing special, I don't know"

U4: Information Difficult to Read
Subjects were asked what they thought about the signs inside the 3D scene, if they understood their functions. **S1, S2, S4:** pointed out that the some information signs in the 3D scene were difficult to read and that the avatar was obstructing the signs.

-*What do you think about the signs? Is it easy or difficult to understand their functions?*

> **S1:** "It was difficult to read when the avatar was standing in front of the signs. The text was difficult to read, I could not read it, but I could have switched off the avatar"
>
> **S2**: "It was difficult to read because the avatar was standing in front of it. But I switched off the avatar"
>
> **S4:** "The function of the signs was easy to understand, but it could be an advantage if one can read the signs from a distance. The signs over the doors were difficult to read. If one can stand in the middle of the room and read the signs so that you don't need to go so close in order to read them. The big signs were easy to read"

Another problem with readability was the dialogue box that pops up after taking a quiz. Two of six subjects (**S3** and **S5**) pointed out that the text in the dialogue box was difficult to read because the font type was too small.

> **S3:** "…It was a small font in the dialogue box"
>
> **S5:** " …What I think can be changed is the font type. It was difficult to read because the font was too small"

Heuristic 2: Minimize the Users' Memory Load
Two breaches were reported about this heuristic principle. These breaches are about information not being available to the users when needed, and about the quiz dialogue box lacking information.

U5: Information not Available when Needed
This usability problem was reported by two of six subjects (**S3, S4**). They were asked if information was available whenever needed.

-*Does dialogues and information remain on the screen while needed?*

> **S3**: "...The dialogue box was not visible before finishing the quiz"
>
> **S4:** " The frame with the quiz questions was too small, so when you got the dialogue box with the score, you could not scroll the frame so you could read the questions and the answers at the same time"

U6: Lack of Information

Subjects (**S1, S3, S4, S6)** pointed out that the dialogue box that pops up after taking a quiz lacks information. That this dialogue box does not give the information needed by the users.

-*What do you think about the dialogue box that pops up after taking a quiz?*

> **S1:** "It was good to read what I answered right and wrong, but it could be better if one can get comments about how much you answered besides the score"
>
> **S3:** "You get what you answered right, and you can try again, but maybe it could also show an explanation of what you answered wrong and your right answers"
>
> **S4:** "It could have been arranged better, you can have more space between the questions and the answers. It could be nice to read what I answered so I could check it and know the right answer, because I don't remember what I answered"
>
> **S6:** "What I missed is what I answered, it is not easy to remember what you answered and therefore it is better to get that information in the dialogue box"

Heuristic 3: Consistency

Two breaches were found about consistency principle: One concerned the button's location and the other concerned the colour code used in the links.

Subjects were asked if they could perform the same actions anywhere in the 3D prototype and expect the same feedback. They were also asked what they thought about the location of the buttons in general and what they thought about the colour used in the 3D prototype.
All subjects agreed that they could repeat the same actions and get the same feedback.

U7: Buttons Location Unseen

Some subjects commented that the buttons location in the web pages should be changed.
S1, S4 and **S5**: pointed out that the buttons located at the bottom of each web page should be placed in another location of the web page.

- *What do you think about the buttons location in every web page?*

> **S1**: "The buttons in the web pages can be moved, you could have one button at the top of the pages and one button at the bottom of the pages. Two of each, if I'm in the top of the page I could click on a button to go down and if I'm at the bottom of the page I could click the top button or back to top link to go up. The buttons are not visible when placed at the bottom of a page because I have to scroll down in order to see the buttons"
>
> **S4:** " The back button could be placed at the top left of each page in case someone clicked on the wrong page and do not want to read that page. They can click on the back button without having to scroll down the whole page in order to go back to previous location. … You can have a back and print button at the bottom of each page and also have a back button at the top of each page so one can escape quickly if you navigate the wrong page"
>
> **S5**: "The back button can be located in a fixed frame so the button won't disappear when scrolling a page up or down"

U8: Weak Colour Code

This usability problem is about the colour code used in the 3D prototype, especially the links. One subject found lack of colour contrast between last visited link and active link:

-Is the same colour used through the whole program?

> **S4**: "The links can have a stronger colour contrast between the last visited link and the active links so you can se the difference between last visited and active link"

Heuristic 4: Feedback /Visibility of System Status

One major breach was reported here. Subjects stated that the system was not keeping them informed about what was happening when interacting with it. That the 3D prototype lacked feedback when interacting with buttons, the VRML browser, the avatar and the 3D scene:
Subjects were asked about the 3D prototype's response when executing an action. Subjects reported some problems about the system not showing status when executing some actions.

U9: Buttons Lack of Feedback

One of six subjects reported lack of feedback when interacting with the buttons in the navigation frame:

- Do you get feedback from your actions when interacting with the 3D scene, VRML browser and the web pages?

> **S2**: " I had some problems with the help button, when I clicked it, nothing happened, I did not see any change because the help page was already there. I expected feedback from the system but nothing happened"

U10: VRML lacks feedback

Three of six subjects reported lack of feedback when interacting with the VRML browser:

> **S4:** "Navigating in the 3D scene was new to me and I did not know what to expect when I clicked on the buttons under the 3D scene or the VRML browser. For instance, the frame with the molecules was very confusing to know what was happening. The buttons in the right frame were difficult to understand. I thought that when I clicked on the buttons something would happen and that I didn't have to click on the window afterwards. But if you compare this with a graphic program it is just the same, you have to click the buttons first and then activate the window and use the mouse pointer to draw. The VRML browser gave little feedback, I did not understood what was happening "

> **S5:** "… It was hard to know how to move the molecules in the VRML browser. I think there were too many buttons and some of them did not work. One thinks that something will happen when you click the buttons, but here one has to choose the button first and then click on the molecule and use the mouse pointer or the arrow keys in order to move the molecule in the desired direction. It is obvious that when a program has a lot of functions it is more difficult to use"

> "I did not like the functions of the VRML browser, it has too many buttons and this is confusing. I think it lacks feedback, especially the go button that deactivates itself after using it one time. One has to choose the go button again in order to zoom in the molecule and I think this was unnecessary"

> **S6**: "Nothing happened when I clicked on the buttons of the VRML browser, but when I understood that I have to click on the window as well, so it was fine"

U11: 3D Scene/Avatars Lacks Feedback
Three subjects reported lack of feedback when using the buttons under the 3D scene, and the avatars:

> **S4:** "It was a bit slow when the avatar entered the portal I clicked on the arrow keys to move the avatar but nothing happened, the avatar did not move because it was moving to another position, but I did not know that"
>
> **S5:** "I did not understand how to move the avatar, I did not understand that I have to click on the 3D scene window in order to start moving the avatar."
>
> **S5:** " I did not understand the function of the buttons under the 3D scene, for instance, nothing happened when I clicked the collide and gravity buttons, but this is because one has to choose the button first and then click on the 3D scene window to activate it. I would have preferred that it was not necessary to click on the 3D scene to activate it every time"

Heuristic 5: Clearly Marked Exits and User Controls

One breach was found about navigation (user controls) not being easy to use.
Subjects were asked questions about all the controls available in the 3D prototype.
The usability problems found here are related to difficulties when navigating in the VRML browser, the 3D scene with avatars and the web pages.

U12: Navigation Problems with the VRML Browser
All six subjects that participated in the evaluation reported problems when navigating in the VRML browser:

-Is it easy or difficult to navigate in the VRML browser?

> **S1**: "It was a bit difficult to navigate in the VRML browser, it has too many buttons"
>
> **S2:** "I think it was slow to navigate in the VRML browser, some of the molecules were far away and I had to drag them or zoom them in and this was slow"
>
> **S3:** "…It has many buttons, but it was not very difficult, but I don't see the point in having so many buttons, some of the buttons were inactive"
>
> **S4:** "It was difficult to navigate in the VRML browser"
>
> **S5:** " It was not very easy and I have some problems with the buttons that were inactive"
>
> **S6:** "It was unusual at the beginning"

U13: Navigation Problems with 3D Scene with Avatars
Two subjects reported problems when navigating in the 3D scene

-Is it easy or difficult to navigate in the 3D scene?

> **S4**: "…I needed help to know how to navigate and use the avatar"
>
> **S6:** "It was unusual at the beginning I got confused when using the avatar and going up and down with it"

U14: Navigation Problems with Web Pages

One of six subjects reported problems when navigating the web pages. These problems were about having to scroll the web page in order to read the whole content of the page.

- *Is it easy or difficult to navigate in the web pages?*

> **S4**: "I think that the frame where the web pages are displayed is too small… there, where you read the text, this frame a bit small. It is better if this frame can be bigger when reading the web pages and then become smaller again"

Heuristic 6: Shortcuts

One breach was found when it comes to shortcuts, this breach was about lacking some common shortcuts typically used in 3D games such as control key crtl + (a,w,s,d)
Subjects were asked if it was possible to use the 3D prototype in a quicker way, whether it was possible to go to a desired position quickly.

U15: Lack of Shortcuts

Subjects reported that they missed some shortcuts in the 3D prototype, especially when navigating with the avatar and when using the home button.

- *Is it possible to go directly to one part of the prototype without having to go through the whole program?*

> **S2**: " I tried to use other keys to move the avatar like A, W, S, and D shortcuts, but this did not function in this program. I am accustomed to use these keys to move around in other programs, but here I could only use arrow keys and the mouse"

One subject reported lack of shortcuts when returning to home location

- *What do you think about the function of the home button?*

> **S1:** " One returns outside the building instead of inside. It could be better if one could return inside the building when using the home button"

One subject reported difficulties understanding the function of the go to button and menu in the navigation bar:

-*What do you think about the function of the go button?*

> **S5**: " It was ok when I understood it's function, but it is labelled go!, and this is English. It can have another label like go to or show and maybe the drop down menu and the go button could be placed closer together so you know they belong together"

Heuristic 7: Help and Documentation

The breach found here concerned the system not having any kind of documentation or written user guide, besides the help function included in the 3D prototype
Subjects were asked what they thought about the help function in the 3D prototype.

U16: Lack of System Documentation
One subject **S4** reported why people do not use help functions in general and what kind of help function is missing in the 3D prototype.

-Do you miss any other type of help function in the prototype?

> **S4:** " The reason why people do not use a help function is because of Microsoft in general, you never get the help you need. When you need help for something, you never get the answer you need. That's why people are sceptical of the use of help buttons"
>
> **S4**: "… I missed documentation about how to use an avatar, a written paper, a user manual that you can read besides the program. A little user guide so you don't miss anything else. I missed instructions about how to use an avatar and how to navigate in the 3D world"

Open Questions:
At the end of the interviews subjects were asked some questions about interaction, appeal, acceptance and motivation. These questions were meant to be open, so subjects could come up with critiques and new suggestions.

Interactions:
Subjects **S1, S5** pointed out that they missed other forms of interactions with the 3D prototype. All other subjects (**S2, S3, S4, S6**) commented that the 3D prototype does not need other forms of interaction.

- Do you miss any kind of interaction with the 3D scene? the VRML browser or the web pages?

> **S1**: "The movie was fine, but I think it could have been better if I could build some molecules myself"
>
> **S5**: "For instance, instead of having the quiz button outside it can be placed inside the 3D world as a sign. You can place it inside so it can be more integrated into what one is doing inside the 3D world. You can have one in each room for each topic. It could be like you have to answer the quiz in one world before being allowed to go inside the other rooms. You can also have a menu that shows how long you have progress in the program, like a game where you get to know that in order to go further you have to answer more questions".
>
> **S5**: " I think the VRML browser was fascinating to see how wonderful the molecules are, the bonding and all the nice design. That's the point with rotation that you can see it from different angles. 'But one can think of trying to build a molecule oneself"
>
> **S5:** "About the web pages, the text was too compressed, you have a heading showing what the page is about, but there are too many topics in the pages… maybe you could have a side menu showing all the topics that one can choose from. The text can be shorter and more topicalized. The web pages have too much text. I try to think as an student, and I see that students have problems dealing with too much information"

Acceptance: Subjects were asked if they would use the 3D prototype to learn more about the carbon chemistry topic. Alls six subjects gave positive answer:

- *Would you use this program to learn more about carbon chemistry topic?*

> **S1:** “Yes, I think so because I don’t know much about this topic yet”
> **S2:** “Yes, to put it plainly, it is better than the text book; you learn more”
> **S3:** “Yes, if I had this as a major topic, I would use this program to get an overview of the topic”
> **S4:** “Well I don’t like 3D very much, but I think this is a good program to use for students, and this together with math programs gives new ways of working in such a way that is fun and students manage well”
> **S5:** “I would use it with students so they learn more about the topic”
> **S6:** “Yes, I would”

Motivation: Subjects were asked if they thought 3D models and the 3D world could be a motivation factor to learn more about carbon chemistry. All six subjects gave a positive answer:

- *Do you think that 3D objects and the 3D scene can be a motivation factor for learning carbon chemistry topic?*

> **S1:** “I think so because it is more interesting to go inside the 3D world and look at the molecules than reading a book. It is more interesting to see 3D models”
> **S2:** “Yes, it can be a motivation factor”
> **S3:”** Yes I think so”
> **S4**:” I think that students will like it, they are very enthusiastic when they are allowed to use the computers and I think this is good for the students”
> **S5:** “I think so, and I think that when one goes around and looks at the models, this is different from reading a book. They get variation. The content in the text is not very different from the textbook, but the fact that they can go around and click and explore and show this like an exhibition, I think it is very engaging”
> **S6:** “I think it can be very motivating because it is something new for students and it is also something they are used to use, it is more exciting than reading a book, which can be dull. So I think this is more useful and exciting for them”

Appeal: Subjects were asked if they thought that 3D visual effects will help to use this prototype. Five of six subjects gave a positive answer:

-*Do you think that 3D visualisation can help to use this prototype?*

> **S1**: “I think it can increase interest for this topic”
> **S2:** “Yes, 3D models make this more real than the book”
> **S3:** “ Yes, it is more exciting so they can move and rotate these molecules and see how they are built together”
> **S4:** “ Yes, it is more entertaining to walk into the rooms than reading a book or a web page. Students are used to computers, so I think simple web pages are boring, but the 3D world, where they can do things and interact with objects, can be an active process and this is good”
> **S5:** “I don’t know, it is more attractive and entertaining because of the 3D objects, I think it may help, but I’m not sure”
> **S6:** “Yes, I think it was a plus that it is 3D. It can be good for youngsters, it can be positive and I think that because they are more used to use chat programs, 3D games and the Internet, this program is not difficult for them to use”

12.3.1 Interview Results Analysis

This section presents an analysis of the usability problems found in the 3D prototype. The data was analysed taking into account each heuristic principle and how many usability problems were found, as well as how many times the same usability problem was reported.
Table 30 notation is as follows: **H**= heuristic principle, from H1 to H7. **U** = usability problem from U1 to U16.

Heuristic	**H1**				**H2**		**H3**		**H4**			**H5**			**H6**	**H7**
Usability problem	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16
Times reported	3	2	1	5	2	4	3	1	1	3	3	6	2	1	3	1

Table 30 Usability problems found in the 3D prototype

Table 30 shows how many usability problems were found for each heuristic principle and how many times the same usability problem was reported.

H1: Speak the Users' Language: Four usability problems were found (U1, U2, U3, U4), where usability problem (U1) for language being too technical or using foreign terms was reported 3 times. (U2) for terms used to explain the topics of carbon chemistry were difficult to understand was reported 2 times. (U3) for the building metaphor implemented in the 3D scene not matching the users conceptual mapping was reported 1 time and usability problem (U4) for information on the signs and dialogue box being too difficult to read because of small font type or lack of space between the text was reported 5 times.

H2: Minimize Users' Memory Load: Two usability problems were found (U5, U6). (U5) for information not being available when needed was reported 2 times and (U6) for the quiz dialogue box lacking information about wrong answers was reported 4 times.

H3: Consistency: Two usability problems were found (U7, U8). (U7) for buttons located at the bottom of web pages should be moved, was reported 3 times. (U8) for links lacking colours contrasts was reported 1 time.

H4: Feedback/Visibility of system Status: Three usability problems were found (U9, U10, U11). (U9) for buttons in the navigation frame lacking feedback, was reported 1 time. (U10) for the VRML browser lacking feedback was reported 3 times and (U11) for the 3D scene's buttons and avatars lacking feedback was reported 3 times.

H5: Clearly Marked Exits and User Controls: Three usability problems were found (U12, U13, U14). (U12) for problems when navigating in the VRML browser was reported 6 times, U13 for having problems when navigating in the 3D scene with an avatar was reported 2 times and (U14) for having problems when navigating the web pages was reported 1 time.

H6: Shortcuts: One usability problem was found (U15). (U15) for lacking some shortcuts for interacting with the 3D prototype in a quicker way was reported 3 times.

H7: Help and documentation: One usability problem was found (U16). (U16) for the 3D prototype lacking a users's guide and documentation was reported 1 time.

The subjects did not grade the severity of the usability problems found in the 3D prototype. For this reason only a summary of which usability problems were most reported by subjects is presented. This may indicate that these problems should be prioritised and fixed during the final review of the 3D prototype.

U12: Navigation Problems with the VRML Browser was the most reported problem. All six subjects reported this usability problem of having difficulties when navigating and manipulating the molecules and using the buttons of the VRML browser. The problems reported concerned the VRML browser having too many buttons and having some buttons disabled.

U4: Information Difficult to Read was the second most reported usability problem in the 3D prototype and was reported by five of six subjects. This problem was about the information signs inside the 3D scene being too difficult to read because either the avatar was obstructing the vision, or because font types were too small both in the signs inside the 3D scene and in the dialogue box after taking a quiz.

U6: Lack of Information was the third most reported usability problem and was reported by four of six subjects. This problem was about not providing enough information, for example, not providing the answer in the dialogue box when subjects gave the wrong answer after taking a quiz.

U1: Language Too Technical or Foreign, U7: Buttons Location Unseen, **U10: VRML Lacks feedback, U11: 3D Scene/Avatars Lacks Feedback, U15: Lack of Shortcuts**.
Each of these usability problems was reported by three of six subjects.

U1: Concerned language used in the 3D prototype in the information frames being too technical and that some of the terms were in English and too foreign for students to understand. For instance, terms such as *avatar* and *VRML browser* were pointed out.
U7: Concerned the location of the buttons in the web pages being unstrategically positioned. Subjects suggested moving the buttons to the top of the pages or to a fixed frame.
U10: Concerned the VRML browser lacking feedback and not giving information to the subjects about what was going on when interacting with the buttons. Subjects did not understand what happened when interacting with this browser, when clicking the buttons no feedback was provided.
U11: Concerned subjects having difficulties when interacting with the 3D scene and avatars. Subject reported having problems when moving an avatar or when using the buttons that controlled the avatars movement under the 3D scene window.
U15: Concerned 3D not having some shortcuts for allowing subjects to use the 3D prototype in a quicker manner. Subjects reported missing shortcuts for moving the avatar more quickly, or having a shortcut to return the avatar to the main hall instead of the entry point, or the shortcut function available in the “go to” button not being positioned closer enough to understand how it worked.

U2: Difficult Terms, U5: Information not Available when Needed, and **U13: Navigation Problems with 3D Scene.** Each of these usability problems was reported by 2 of six subjects.

U2: concerned some terms used to explain the subject of carbon chemistry being too difficult to understand by some subjects.
U5: concerned the quiz dialogue box not being available before finishing a quiz, the frame with the quiz question being too small to show all of the questions in the frame and the score, thus information was not available when needed.
U13: concerned having navigation problems when interacting with the avatar because subjects did not know how to move the avatars.

U3: Interface Metaphor Unclear, U8: Wrong Colour Code, U9: Buttons Lack of Feedback, **U14: Navigation Problems with Web Pages, U16: Lack of System Documentation.** Each of these usability problems was reported only by one of six subjects and needs no further analysis.

Diagram 2 shows the usability problems and how many times they were reported

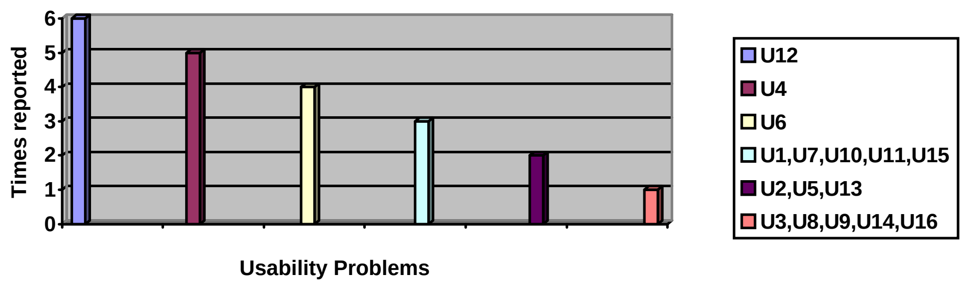


Diagram 2. Reported usability problems

In total, 16 usability problems were reported
The diagram 3 below shows the heuristic principles H1- H7 and how many breaches (usability problems) were found in each heuristic principle ranging from 1-4 breaches

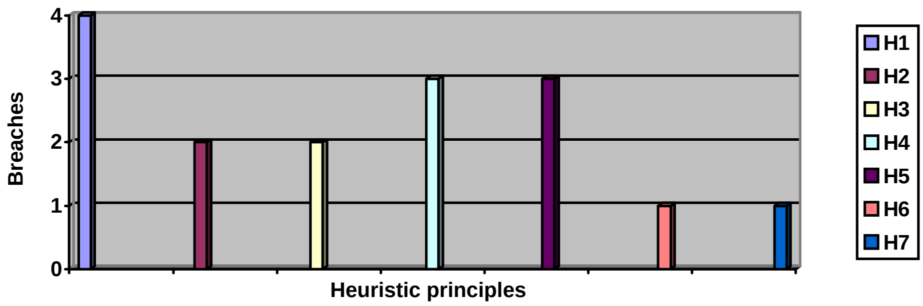


Diagram 3: Heuristic principles' breaches

The following section presents the weakness and the strengths with the evaluation of the 3D prototype.

12.4 Weakness and Strengths of the Evaluation

This section presents a summary of the weaknesses and strengths of the evaluation of the 3D prototype. The discussion will take into account the formative evaluation stages and the usability methods applied (questionnaires, observations and interviews)

12.4.1 Strength and Weaknesses of the Formative Evaluation Stages

During the evaluation of the 3D prototype two formative evaluation stages were applied:
One expert review and six one-to-one evaluations (usability test).

Expert review vs. One-to-one Evaluations
The expert review was conducted with one teacher (expert) while the usability test was performed with 6 end-users (2 students and 4 teachers).

According to Tessmer (1993), there are several advantages and disadvantages in performing an expert review over the use of other formative evaluation stages.
One of the major advantages of an expert review is that it does not use learners, but people that have knowledge and experience that novice users do not have. This provides a wide array of information about the content quality that novice users cannot provide.
A disadvantage of an expert review is that it cannot provide performance or opinions from a learner's point of view. An experts point of view about instructional effectiveness and learners' appeal is inferential and sometimes the opposite to what learners think is good or bad instruction (Tessmer, 1993).

When it comes to one-to-one evaluations, one major advantage of performing one-to-one evaluation with end-users is that it elicits information from the end-users point of view. No expert evaluation can provide the perspective and reactions of a learner from the target population.

One disadvantage of one-to-one evaluation is that these evaluations do not involve a great number of end-users, may therefore not be representative of the target population. Furthermore, one-to-one evaluations are performed with end-users, which depend primarily on the user's opinion and performance.

During the evaluation of the 3D prototype, only two learners (two 10^{th} graders) participated in the usability test. The other subjects were experts although they also are end-users since the 3D prototype is supposed to be used by both learners and teachers. So the greatest disadvantage of the evaluation might have been not including more students (10^{th} graders) in the evaluation with different skill levels. Another point to notice is that the two 10^{th} graders that participated in the formative evaluation were above average learners with high level of computers skills. Using below average learners under the evaluation would have given a different set of usability problems, but it would have been difficult to distinguish between what was a usability problem and what was an ability problem, because of lack of computer skills. On the other hand, the major strength of the evaluation might be the fact of using expert teachers for reviewing the 3D prototype, since experts come up with many suggestions for improving the interface.

12.4.2 Strength and Weaknesses of the Usability Methods

Three methods were used to gather data during the usability test of the 3D prototype: questionnaires, observation and interviews. These data gathering methods have both advantages and disadvantages.

Questionnaires: have the advantage that they can be administered to many users and are answered quickly. However the major disadvantage of this method is that it is not flexible and subjects answer questions without further explanation. Further, questions are difficult to design without performing a pilot test.

Interviews are very flexible; the questions asked to subjects can be further clarified and deepened. Interviews are effective for eliciting information about users preferences, and impression, and opinions about the interface. The major disadvantage of interviews is that they only elicit information about users' opinions of the interface and not about the actual performance while using the interface.

Observations: is a very simple method, since the evaluator watches the subjects while using the interface and takes notes. The major advantage of this method is that by observing users performing tasks with an interface, the evaluator discovers that the interface may be used in unexpected ways. The major disadvantage of this method is that it is difficult to know what users really think about the interface, though the evaluator only interprets what is visible to the eye not knowing what the user may think of the interface.

According to Jakob Nielsen (1993), from a usability perspective, questionnaires and interviews are indirect methods; since they do not study the user interface itself, but only users' opinions about the user interface, and this might be the greatest weakness of the evaluation methods used. The usability test came up with a series of usability problems that have to be fixed in the final review of the 3D prototype.

Both methods, observation and interviews try to uncover usability problems as much as possible, however, subjects were not asked to range the severity of the problems they reported because it would have been necessary to use a heuristic evaluation method instead of interviews. A heuristic evaluation was not considered because the students were far too young to understand the complexity of evaluating the user interface and grading the severity of the problems. For this reason it was decided to use observation and interviews instead of heuristic evaluation.

The next section presents a discussion part of this thesis. First a series of suggestions for improving the 3D prototype are discussed, followed by the conclusions.

13 Discussion

This section presents first a discussion of some suggested improvements that can be implemented in the 3D prototype. The suggestions are presented first, followed by a screenshot presentation of some of the suggested improvements. At the end, a discussion and conclusions are presented.

13.1 Suggested Improvements

Several suggestions to improve the 3D prototype arose during the evaluation phase.
The 3D prototype can be improved by taking into account the following suggestions:

- Use Norwegian instead of English terminology to explain terms that users understand more naturally, in other words, by speaking the users' native language.
- Choose a bigger font type to make information more readable. This applies to information signs inside the 3D scene and the dialogue box when taking a quiz
- Make the dialogue box for the quiz and the questions available at the same time so that users may read the questions and the score with the answers simultaneously
- Provide more information in the dialogue box after taking a quiz, e.g. both right and wrong answers
- Position the buttons of the web pages at the top of the page or to a fixed frame
- Change or increase the colour contrast between the visited and active links
- Change the VRML browser used in the 3D prototype for another more user-friendly browser, as for instance Blaxxun Contact 5.1 or RasMol plug-ins
- Make the information frame that displays web pages larger so that users do not have to scroll down the pages in order to read the information
- Position the "go to" button and the drop down menu so that users understand that these two controls function together
- Provide more feedback when navigating in the 3D scene with avatars by giving information when avatars move through portals
- Include some other kind of shortcuts, like placing the avatar in a desired position and not only allowing the avatar returning to entry point
- Make the 3D scene with avatars more interactive by including the quizzes inside the 3D scene
- Provide the possibility for users to build their own molecules inside the 3D scene
- Include a user guide or system documentation to be delivered with the final version

All of these suggestions for improving the 3D prototype can be implemented, however, due to the time constrain of this thesis, and because a new design cycle is needed, only some of the suggestions mentioned above are presented in the next section, with examples of screenshots manipulated with MS Paint. The screenshots shown below are not yet implemented in the 3D prototype.

13.2 Re-designing the 3D Prototype

The following suggested improvements are presented in this section:

1. Provide more information in the dialogue box after taking a quiz, e.g. both right and wrong answers
2. Position the buttons of the web pages at the top of the page or to a fixed frame
3. Position the "go to" button and the drop down menu so that users understand that these two controls function together
4. Change the VRML browser used in the 3D prototype for another more user-friendly browser, as for instance Blaxxun Contact 5.1 or RasMol plug-ins
5. Make the 3D scene with avatars more interactive by including the quizzes inside the 3D scene
6. Provide the possibility for users to build their own molecules inside the 3D scene
7. Provide more feedback when navigating in the 3D scene with avatars by giving information when avatars move through portals

Suggestion 1: Provide more information in the dialogue box after taking a quiz, by including both right and wrong answers. This is possible by including the wrong answers with another font type, as for instance, bold. Figure 62 shows and example of how this dialogue box may look. The new feature is presented in bold font type.

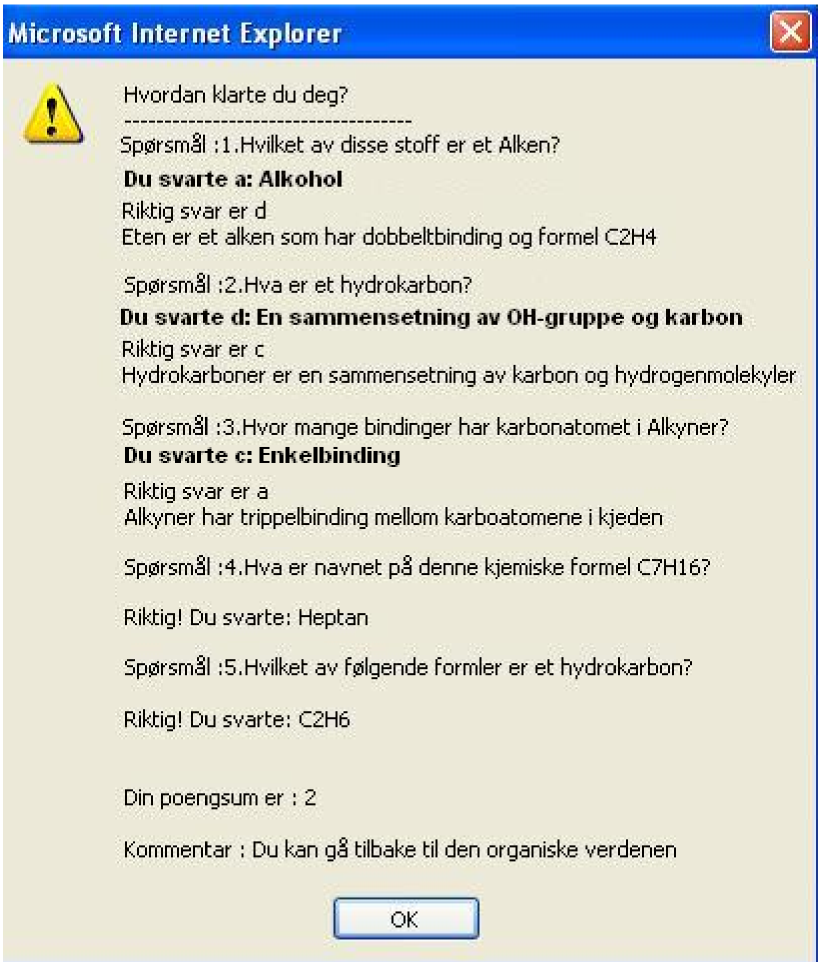


Figure 62 Improving the quiz's dialogue box

Suggestion 2: Another suggestion was to position the navigation buttons (back and forward buttons) of the web pages to the top right side of the pages. (Figure 63: A) shows a web page with the navigation buttons positioned at the top of the page.

Bevegelser	tastatur
Framover	Pil opp
Bakover	Pil ned
Venstre	Venstre pil
Høyre	Høyre pil
Stige opp	Shift+pil opp
Stige ned	Shift+pil ned
Vipp syn opp	Ctrl+pil opp
Vipp syn ned	Ctrl+pil ned
Fly til venstre	Shift+venstre pil
Fly til høyre	Shift+høyre pil

Figure 63 Moving the navigation buttons to the top right side of a web page

Suggestion 3: Locate the drop down menu and the “go to” button so that users understand that these two controls function together. One way of implementing this new feature is to enclose the drop down menu and the “go to” button in a frame, in order to indicate that these two controls function together. (Figure 64:A) shows how this feature may be implemented in the navigation bar of the 3D prototype.

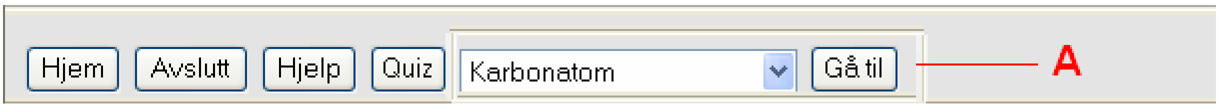


Figure 64 Enclosing the drop down menu and the “go to” button in a frame

Suggestion 4: One important improvement suggestion was to change the VRML browser used in the 3D prototype for displaying the molecules for another tool that is more user-friendly, as for instance, Blaxxun Contact plug-in. (Figure 64:A) shows a screenshot of Blaxxun Contact. This plug-in was installed in a personal computer to show an example of how it works. Blaxxun Contact 5.1 plug-in has no buttons at all, and allows 3D object manipulation with the mouse or keyboard, thus making it easer to use. The reason why this plug-in was not used in the 3D prototype was because of a known bug that sometimes displays the VRML code text instead of the 3D rendered object.

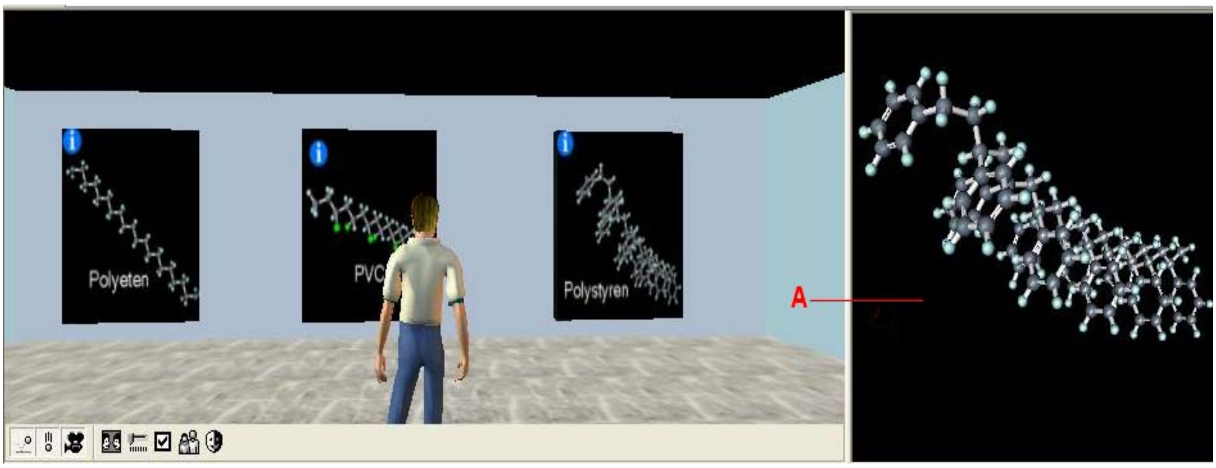


Figure 65 **Using another VRML browser: Blaxxum Contact 5.1**

Suggestion 5: Another major suggested improvement to the 3D prototype was making the 3D scene with avatars more interactive by including the quizzes inside the 3D scene. Figure 65 shows and example of how this feature can be implemented. The image shown below is not yet rendered, an exiting screenshot was used and the new feature (Figure 65: A) has been added with help of MS Paint. The new feature shows a sign with a button that users can click and display the quiz questions in another frame.

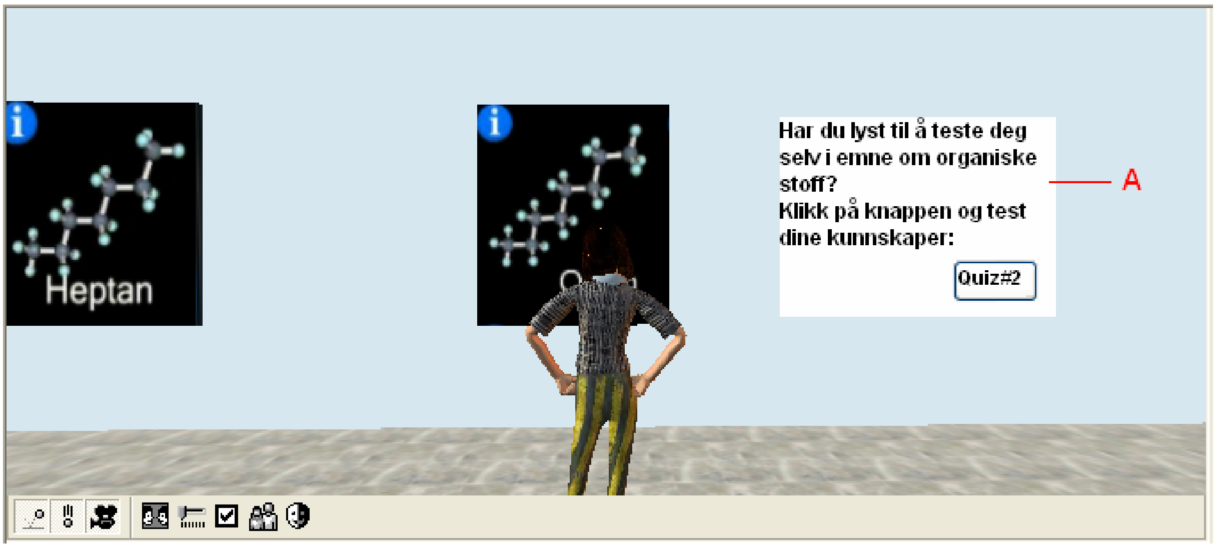


Figure 66 **Including a quiz inside the 3D scene**

Suggestion 6: In order to make the 3D scene more interactive, some subjects suggested having the possibility to build their own molecules inside the 3D world. (Figure 66:A) shows an example of how this could be implemented. The new feature was added with the help of MS Paint. In order to implement this functionality, a lot of programming work is needed, as well as using a third-party application as for instance, Viewpoint Scene Builder, which allows the implementation of advanced features that can be imported inside 3D worlds.

Figure 67 Building molecules inside the 3D scene

The idea is to make a box that contains combo-boxes where users can choose the type of model they want to display: capsel, ball&stick, wireframe, space-filled. Users can also choose the type of atomic bonds: single, doble and triple. Users can also choose the type of atom: hydrogen, oxigen, carbon, etc., and how many atoms should the molecule contain. Figure 67: A shows two buttons, one to reset the options and one to submit and build the molecule. The molecule can be displayed in a VRML browser.

Suggestion 7: This suggested improvement was about providing more feedback when navigating inside the 3D scene with the avatars. For instance, some subjects complained that when the avatar was going through the portals, the 3D scene did not give any kind of information about what was going on with the system. In order to give more feedback, one can provide a progress bar with a textbox displaying a message when the avatars go through portals. (Figure 67) shows an example of how this could be implemented, for instance, a progress bar with a message on it could be added inside the 3D scene (see Figure 67:A)

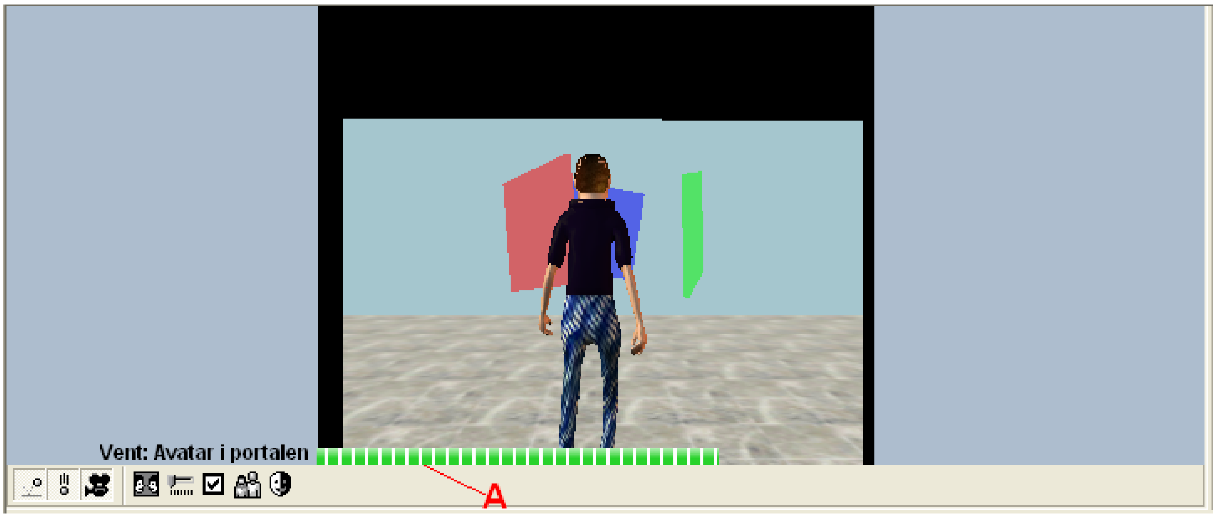


Figure 68 Providing feedback. A progress bar showing system status

More improvement suggestions arose during the evaluation as listed in the previous section, however, presenting all of these design suggestions without having the participation of the intended end-users could result in an erroneous design. It is important to remember that system designers usually do not think as end-users do. Users should be involved in the design process. In order to redesign the 3D prototype, another cycle of iterative design and development is needed with the participation of end-users during the design phase.

The next section presents some personal insights and the conclusions of this thesis.

13.3 **Conclusions**

This section gives some personal insights about what was learned during the process of writing this thesis. An insight of what could have been done differently is also presented.

When I started this thesis, the main purpose was to design and develop a web-based 3D learning prototype for learning natural science for the 10^{th} grade. In the beginning, the plans were to develop a complete learning environment that would include all subjects of the natural science curriculum. This turned out to be too ambitious and almost impossible to accomplish within three semesters. I soon realised that the subjects to be implemented in the 3D prototype had to be narrowed down, in order to fulfil the thesis within the three semesters. By concentrating on one subject of natural science, carbon chemistry, I had time to gather as many resources as possible in order to get a good insight about the subject matter. Furthermore, the subject of carbon chemistry had to be narrowed down in order to fit the curriculum of the 10^{th} grade.

The process of design and development was time consuming and turned out to be a difficult task. During the design of the 3D prototype some problems arose. Since I concentrated in the subject of carbon chemistry, I spent a lot of time finding and producing all of the molecules that were to be implemented. Another problem that had to be solved was how to communicate and work together with two students of age 15. The main problem was that these two students had no experience with designing interfaces of any kind, but they were above average learners, with a high level of computer skill. I found that I had to explain to them very thoroughly what was expected of them. I explained to them what a 3D learning environment was and showed them some examples. I also explained what prototyping was and showed them some examples of how to make paper mock-ups. In order to get full benefits from these two students involvement, it was necessary to present a suggested paper prototype. For this purpose, a paper mock-up was presented to them, so they were prepared for the coming design session.

Working with youngsters was an enriching experience; they came up with so many creative ideas that if I had had the time, I would have implemented many of them.
Deciding which ideas to implement was a hard process, but finally, I came up with a design model that included most of the ideas suggested by the students with some modifications. After finishing the design phase, the task ahead was to develop the 3D prototype and test it on the Web.

The development phase was also a time consuming activity. First I had to learn how to master and use a 3D vector-geometry building tool called Atmosphere Builder. I tried and failed many times before mastering how to build and position each 3D object to be included in the 3D prototype. I learned that working with 3D objects is complicated. Building a 3D environment using 3D vector geometry, where each object is built using x, y and z coordinates in order to describe the object's shape and position in space, is a time consuming and a difficult activity. It took longer time than expected. Another problem faced during development phase was my lack of programming experience with VRML and JavaScript programming languages. The 3D objects implemented in the 3D prototype and the web pages were programmed using JavaScript; while all of the molecules were programmed using VRML language. After much trial and error, I finally learned the necessary skills to produce all of the 3D objects and web pages needed to implement the 3D prototype.

During the evaluation phase, some other problems arose. To begin with I wanted to evaluate the 3D prototype with the whole class. This turned out to be far too ambitious, since I was both designing and implementing the 3D prototype. So I had to narrow down my ambitions and decided to do a formative evaluation. First an expert review was done with one teacher, then a usability test was carried out with 5 expert teachers and two students.
The evaluations were performed as planned and without any kind of technical difficulties. However as I pointed out earlier, I would have done the evaluation differently and included more students with different levels of skill, instead of including only two above average students. This could have given a different result of the evaluation and pointed out other usability problems that should be taken into account when considering weaker students.

After performing the evaluations and analysing the data, I realised that some usability problems could have been avoided, such as the problems about using English terms instead of Norwegian, especially when talking about VRML browser and avatars. I could have thought of a Norwegian term instead.

Another thing that I could have done differently was the VRML browser chosen for showing the molecules. The chosen browser had so many buttons and functions, making it a difficult tool to use for both teachers and students. I should have chosen another tool for displaying the molecules, for instance, Blaxxun Contact 5.1 (as shown in Figure 65:A) that have fewer controls, thus making object manipulation more intuitive.

Another point that I could have done differently was the amount of interactivity included in the 3D scene. I could have included more interactivity in the 3D scene, by implementing the quizzes inside each room and allowing the users to construct their own molecules.
When implementing learning environments it is important to have several methods for assessing leaning. The 3D prototype does not provide the teacher with the possibility to assess how much the students have learned. This is a fair criticism and something that I should have designed more carefully.

Finally, there are always things that could have been done differently when designing and developing interfaces. However, one is not aware of the problems and errors that may be encountered before facing them and testing the interface with end-users. That is why it is important to perform ongoing evaluations during the design and development phases with end -users, in order to discover early as many usability problems as possible. Including end-users during the planning, design and development phases of an interface is time consuming, but it is worth the effort, since it is the end-users, not the software designers or program developers, who will use the new interface. Evaluating an interface is a time consuming process, but it pays off by saving developing time, since design errors are discovered before implementation is done. The process of trial and error is an invaluable experience for a software designer, since it avoids making the same mistakes again when designing and developing other interfaces.

The process of designing, developing and evaluating a 3D prototype for the purpose of learning was an interesting and challenging experience, which I most enjoyed. I personally liked working closer with middle school teachers, because of their teaching experience and for providing so many constructive suggestions for improving the 3D prototype. Working with two young students was a very positive and challenging experience, because they have a creative mind that is certainly needed when designing and developing 3D worlds for educative purposes.

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