Tampereen teknillinen korkeakoulu
Julkaisuja 381

Tampere University of Technology
Publications 381

Harri Ketamo

User and Platform Adaptation in Web-based Learning Environments

Tampere 2002

Tampereen teknillinen korkeakoulu
Julkaisuja 381

Tampere University of Technology
Publications 381

Harri Ketamo

User and Platform Adaptation in Web-based Learning Environments

Thesis for the degree of Doctor of Philosophy to be presented with due permission for public examination and criticism in Auditorium 126, at Tampere University of Technology, Pori, on the 14th of August 2002, at 12 o'clock noon.

Tampere 2002

ISBN 952-15-0860-4 (printed)
ISBN 952-15-1506-6 (PDF)
ISSN 0356-4940

TTKK- PAINO, Tampere 2002

Abstract

The aim of this thesis is to provide new empirical knowledge and case solutions to the domain of user and platform adaptive learning environments. The studies of the thesis were based on reviews of literature, technological development and empirical studies. The empirical studies were done in controlled situations during the years 2000-2002. The empirical data was analyzed using quantitative and qualitative methods. All software described in this thesis was written especially for research purposes in order to ensure the efficient collecting of observation data.

In the first study PDA's and PC's are compared in order to find out empirical knowledge for platform adaptive learning environments. The clearest result was that the touch screen PDA's enable more effective human-computer interactions than the touch screen of PC's or the use of a mouse. Technological use of PDA's was also easy to learn. Contrarily, readability in the PDA platforms was poor.

A user behavior adaptive learning tool (Adaptive Geometry Game) was developed and studied empirically in this thesis. The game was empirically tested on a PDA platform and it seemed to work well. Over 60% of the pupils reached the higher skill group after playing the game. What is more important, all the low skill pupils reached average skills in geometry after playing the game. The rules for optimizing the learning outcome were discovered with careful observation of the learning situation in the first stage of the study. According to this study, when developing the user behavior adaptive system we should first focus on the elements or factors we plan to observe.

A web-based platform adaptive group working environment, xTask, was implemented for this thesis. xTask was used in the empirical study, the aim of which was to find out differences in using processes between PDA and PC platforms. In this study the use of a PDA platform was approximately 20% of all use. PDA's were used mostly for reading documents and giving short answers to group members while most writing was done with PC's. Different use of platforms did not explain anything about learning outcomes. Encouraging and supporting processes in groups could have explained learning outcomes.

When combining these results, we can say that PDA's and PC's can not be used as equal platforms for learning environments. We can even say that PDA's can not replace PC's in education, although there are some areas in which PDA's can provide more versatile opportunities for learning than PC's.

Preface

This thesis is based on work carried out during the years 1998-2002. The oldest parts of the thesis were started when I was working as a teacher in Nakkila. Studies continued when I worked at the University of Turku in the department of teacher education in Rauma, where I got my licentiate degree in educational sciences. The main studies of the thesis and the most important findings were made after the year 2000 while at the Tampere University of Technology, Pori. During this work the original idea about an effective learning game for geometry grew much larger than I first supposed.

I would like to express my gratitude to my supervising professor, Jari Multisilta, for his guidance on this thesis, as well as for the new ideas and support I have received during this work. With his help I was able to apply my previous studies about learning materials and learning environments to technology research without forgetting the importance of human elements. I would also like to thank professor Peter Brusilovsky and professor Erkki Sutinen for feedback and ideas when pre-examining this thesis.

I wish to thank Dr. Lauri Kemppinen, Ph.D for good co-operation when working on our usability studies, which are partially presented in this thesis. I would also like to thank Dr. Jyrki Suomala, Ph.D for co-operation between the years 1998-2000, professor Kari Niinistö for supervising my licentiate thesis, which serves as a background for one part of this thesis, as well as the personnel in Advanced Multimedia Center at the Tampere University of Technology, Pori.

My research work received funding from several sources: Tekes, The Finnish Cultural Foundation (Satakunnan maakuntarahasto), the High Technology Foundation of Satakunta (Satakunnan korkean teknologian säätiö) and the foundation of Ulla Tuominen (Ulla Tuomisen säätiö). I wish to acknowledge their support. I would also like to take this opportunity to thank Dr. Ari Alamäki, Ph.D from TietoEnator Oyj and Mr. Raimo Ratilainen from Lännen Puhelin Oy for co-operation within the research projects related to this thesis.

Finally I would like to thank my parents, Mirja and Juhani, my grandmother, Ester, and my wife, Nina, who have encouraged me during my studies.

Contents

List of Figures

List of Tables

1 Introduction

Education plays an important role when building a real information society, a society with easy access to information services. Utilization of information services, which is one of the ideologies behind eEurope, requires technological literacy. In order to optimize learning outcomes by using information and communication technologies (ICT), we have to create learning systems that can adapt to the users' needs.

The World Wide Web (WWW), wired or wireless, offers good opportunities for producing and delivering different types of learning material. Since 1994 when the first pedagogically planned learning materials, such as Matrix Algebra (Multisilta 1996), were designed in the web, the environment has developed a lot. While the first web-based learning materials could be categorized as 'living books', soon the first collaborative web-based environments appeared. Astronomy On-Line was one of the first large scale co-operative learning environments (Multisilta 1997a). This thesis introduces solutions and ideas for the next generation of the web-based learning environments as platform and user behavior adaptive systems.

In this thesis adaptation is studied from two perspectives, based on Brusilovsky's (2001) categorization: 1) the program's adaptation to the user's behavior, 2) client device adaptation.

From the platform adaptation point of view the differences between PC's and Personal Digital Assistants (PDA) are important to study in order to ensure that future learning platforms can be utilized with the best possible devices, in accordance with given tasks. This thesis provides new results especially in the field of human-computer interaction and readability between different technological platforms. In this thesis the term PDA refers to a small hand-sized computer, such as Compaq's iPaq, HP's Jornada and Nokia's Communicator.

The main theme within user behavior adaptation in this thesis is finding out, if adaptation rules can be defined using traditional statistical methods. When comparing statistically modeled adaptation rules to self organizing adaptation rules, we can say that self organizing based rules are more flexible, but they are also more dependent on the way in which they were taught at the first time. Statistically modeled rules have to be formulated beforehand, but they can have two benefits: Firstly, they really exist if they are found in the observed data, and secondly, the rules executed in the server can be implemented as computationally efficient. In this thesis statistical rules have been found for an adaptive geometry learning game. This result is remarkable in order to prove that adaptation does not have to be based on neural networks, although, in general, neural networks have several benefits over traditional statistics.

1.1 Definitions

In this chapter key concepts of the thesis are defined. Some of the key concepts will be later defined in more detail in the context of the studies.

According to constructivism, people actively construct their own knowledge through interaction with the environment and through reorganization of their mental structures (Resnick 1989; Phillips 1997; Chi & Bassok 1989). Constructivism is not an integrated theory, but it can be divided into cognitive constructivism and social constructivism (Phillips 1995; Phillips 1997). Both cognitive constructivism and social constructivism share the view of the learner's active role, but in a different way.

Cognitive constructivists are concerned with individual activity: Learners construct knowledge and store this knowledge in their inner mental structures (Phillips 1997). In addition, psychological mechanisms that are responsible for this constructive activity are essential, and cognitive constructivists give priority to individual students' sensory-motor and conceptual activity (Cobb 1994).

Social constructivists are interested in the question of how the public representations of knowledge are constructed (Phillips 1997). They are mainly focused on the public understandings that are available in a culture. Learning is seen as a process, in which an individual constructs his or her understanding in interaction with other individuals. From this perspective, the main issue is to explain how participation in social interactions and culturally organized activities influence the development of individuals (Cobb 1994).

In this thesis learning is understood as a constructive process. The user's behavior in digital environments is understood as a result of their inner processes. Even though we can not observe these inner processes we can observe some of their physical representations, as in the readability study in Chapter 4. Especially in Chapter 5 the constructive nature of learning processes has been the focus: Good learning outcomes are assumed to be reached by supporting mentally active thinking processes in the web-based learning game. In Chapter 6 the empirical study is based on idea of social constructivism. In this study co-operation in the web-based environment was seen as being a background for the learning processes.

Web-based learning environments can provide materials for studying, communication features for teaching and collaboration, workspaces for students, testing possibilities and cognitive tools (Multisilta 1997b). Most of the recent computer-based learning environments are also web-based, therefore web-based learning environment and learning environment are used as synonyms. A group work environment is also used as synonym for a web-based learning environment when the focus of the environment is on collaboration.

PDA's use a wireless network within all the studies in this thesis and wireless is seen as being a preference of PDA's. Though a wireless network provides new possibilities for studying, the network layer is invisible to the user and therefore different network technologies are not discussed.

As defined before, learning is an active process in which the learner's mental structures are developed. The learning environment concept describes that there exists an environment for learning processes: a place for study. Tella & al. (2001) uses the words teaching, studying and learning to define the differences between the learning process and the learning environment.

eLearning as a concept refers to enterprise training and it describes that computer-based learning environments are used to provide training. eLearning uses web-based course materials or other parts of learning environments. In this thesis eLearning is understood as being synonym for web-based learning.

From the perspective of constructive learning theories the following properties might be required of a good web-based learning environment: 1) The environment must support a student's active work, 2) the environment must enable social interaction so that co-operative or problem-based learning tasks can be implemented, 3) it should be possible to share knowledge, tasks, and objectives in the environment, 4) it should be possible to arrange testing and examinations in the same environment, 5) the environment should support the giving of feedback, 6) the environment should be open and capable of extension. It should be possible to add other teaching materials, documents, and tasks to the environment and 7) environment navigation should be designed to instruct and guide the user. (Vivet 1996; Ruokamo & Pohjolainen 1998; McGee & Howard 1998; Maurer 1996; Hopper 1998; Lehtinen 1997; Multisilta 1997b; Oppermann 2002).

In this thesis adaptation is studied from two perspectives: 1) the program's adaptation to the user's behavior, 2) client device adaptation (Brusilovsky 2001). In the user behavior adaptive system user modeling is used in order to support user's performance. In client device adaptation the same content is delivered into different platforms.

The conceptual difference between personalization and adaptation depends on the decision maker: When the user makes decisions about the using process, the system is personalized, but when the machine makes the decisions according to some rules the system is adaptable. The background for adaptive systems is in user observation. User observation, its limits and obstacles, are discussed in the context of a usability study. The biggest obstacle within adaptive systems stems from user observation: We can not get reliable user data when we do not know the environment and the context in which the user data is recorded (Brusilovsky 2001).

In this thesis observation is seen as a data-collecting method. In the studies, described in Chapters 4-6, observation is done by a program, which records all human-computer interaction on a log file. This kind of observation is invisible to users in the terms of Loomis & Blascovich (1999) and therefore it is ecologically more valid (defined in Chapter 3.2) than observation based on video recordings.

Cognitive tools are utilized to support cognitive processes of learners in order to improve thinking, for example by organizing information with mind maps (Jonassen & al. 1997; Pea 1994). The cognitive tool should affect reflection in which the learner is forced to evaluate his own conceptual structures and assimilate a new issue to existing conceptual structures (Jonassen 1994). Cognitive tools should be seen as learning objects and there should be a program level interface for open learning environments (van Joolingen 1999). Especially small cognitive tools for specific purposes, which can be reused in several contexts, should be made into learning objects (Kay 2001). In this thesis the Adaptive Geometry Game in Chapter 5 is a cognitive tool.

1.2 Structure of the thesis

The study begins with a general description of the aims and the methods of the study in Chapter 2. In this Chapter the design of the research and general research questions of studies are described in order to give the reader a preview of the thesis.

In Chapter 3 the definition of and introduction of concepts and issues related to adaptation, observation and cognitive tools are presented. The defined concepts and ideas are used within all studies.

In Chapter 4 the usability of different client terminals (such as laptop computers and PDA devices) are studied in terms of interaction, recognition and readability. These approaches were selected, because they provide interesting information for the planning and implementation of adaptive systems.

Chapter 5 includes the most important study in this thesis. The development of user behavior in the Adaptive Geometry Game is done in two stages, which both include empirical data analysis. The Adaptive Geometry Game itself can be seen as a result of the study. On a more general level, this study shows that a simple set of adaptation rules can be found to optimize the learning result in well-defined and focused learning tasks.

In Chapter 6 an adaptive working environment, xTask, is described and evaluated according to results from the empirical study. There are a few new tools in xTask that are used in the empirical study. Especially the document development area, which is a combination of a text editor program and a discussion forum, is studied. The idea of creating a platform adaptive system for PC and PDA was new in 2000, when the development of xTask started.

In Chapter 7 the results of the studies are summarized and evaluated. The Chapter is divided into two subchapters, the first of which focuses on results from the platform adaptive point of view and the second focuses on results from the user behavior point of view.

2 Research design

The aim of this thesis is to provide new empirical knowledge and case solutions to the domain of user behavior and platform adaptive learning environments. This is done in four empirical studies which all include a technical development. The empirical studies are:

1) PDA's and PC's as learning platforms -study in Chapter 4, the aim of which is to find empirical facts about a user's behavior in different platforms.

2) Study factors of learning outcomes (Chapters 5.3 and 5.4), the aim of which is to develop a model for increasing learning outcomes with user behavior adaptation.

3) Study of the Adaptive Geometry Game (Chapters 5.5 - 5.7), the aim of which is to implement and test the user behavior adaptive learning game, based on results of studies 1 and 2. The Adaptive Geometry Game is also platform adaptive.

4) Study of xTask – a platform adaptive group work environment – in Chapter 6, the aim of which is to develop a platform adaptive group work environment and empirically find facts about a user's behavior in this environment. This study uses Study 1 as background when evaluating the tools or empirical results.

The empirical studies can be divided into basic research or applied research. Studies 1 and 2 are basic research and studies 3 and 4 can be seen as applied research. Studies are also divided into platform adaptation studies or user behavior adaptation studies, according to the focus of the study. In Figure 1 the roles and relationships of the studies are described.

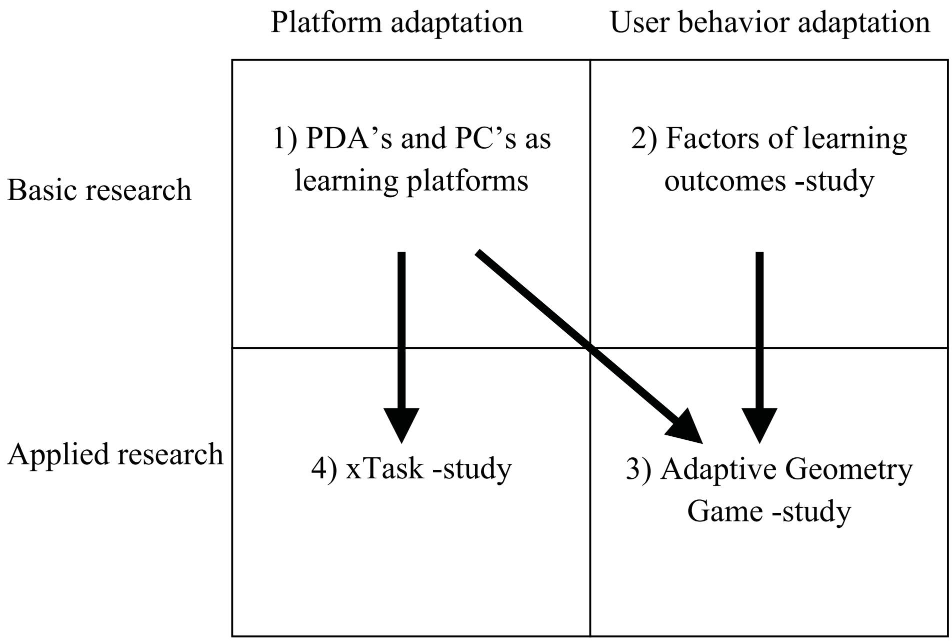


Figure 1. Roles and relationships of the studies.

The specific research questions are presented at the beginning of each study. In the following research questions and methods for studies 1-4 are described at a general level.

Study 1: PDA’s and PC’s as learning platforms:

1. What differences can be found in the speed of interaction between a PC and PDA environment?
2. What differences can be found in the reading speed between a PC and PDA environment?
3. What is the importance of the user’s age for the usage of PC’s and PDA’s?

Study 1 is an empirical study and qualitative methods are used in the analysis. The sample of the study was collected during 2001 from schools and universities in the Satakunta region. The size of the sample is 469.

Study 2: Factors of learning outcomes:

1. What kinds of general learning results have been achieved with different learning materials?
2. Can the learning results be explained by the use of learning material?

Study 2 is an empirical study. Qualitative methods are used in the analysis of collected data. The sample of the study was collected in March 2000 from kindergartens and pre-schools in the Satakunta region. The size of the sample is 71.

Study 3: Adaptive Geometry Game:

1. What is the learning outcome with the Adaptive Geometry Game?
2. Do the adaptation rules work as expected?

Study 3 is an empirical study which includes technical development. Technical development focuses on implementation of the learning outcome optimizing rules, found in study 2. In the empirical part, qualitative methods are used in the analysis of collected data. The sample of the study was collected in January 2002 from pre-schools in the Satakunta region. The size of the sample is 17.

Study 4: xTask – a platform adaptive groupwork environment:

1. How does the implementation of the platform adaptive environment work?
2. What kinds of future developmental ideas can be found in terms of user behavior adaptation?

Study 4 is about technical development and it includes an empirical study. Technical development focuses on the implementation of a platform adaptive group work environment – xTask. The empirical study is about a university course that was carried out with the xTask environment. In the empirical part only basic quantitative methods are used to describe the utilization of the environment, most of the analysis is based on qualitative methods. The sample of the study was collected during May 2002 at the Tampere University of Technology, Pori. The size of the sample is 10.

3 Literature review

In this chapter the most important themes of the thesis are examined using recent studies in the field. This chapter provides background for the research questions by showing the limitations of available studies and the need for future research as indicated by literature.

Chapter 3.1 begins with a literature-based analysis of current adaptive systems research. This should provide a view on the history of adaptive systems and current research as well as provide background for future research needs.

In Chapter 3.2 background on observing the behavior of users is discussed in terms of ecological validity. Measuring the behavior of users is the key issue within adaptive systems. Therefore it is important to recognize the limitations of the observation systems, as well as all the issues that bring uncertainty to the analysis of user behavior.

Chapter 3.3 is about cognitive tools. Later in this thesis the ideas of adaptive systems are incorporated into cognitive tools in order to build even better cognitive tools. Cognitive tools are a major concept within the learning environments as well. All tools that are built to improve learning can be understood as being cognitive tools.

3.1 Adaptive systems

Adaptive systems can be divided into several categories. Brusilovsky (2001) present a high level categorization for the concept of adaptive systems: 1) Adaptation to the user's behavior and 2) adaptation to the client device.

1) The system can adapt to user behavior by using user models or user data. User models were the most examined area in adaptive systems until 1996. The user models are based on the idea that users can be classified into categories and that there are similarities in user behavior within the categories. Since 1996 user data adaptation has been studied. User data adaptive systems do not use categories for modeling; they accept that the behavior can not be described by specific categories (Brusilovsky 2001; Kobsa & al. 1999). These systems utilize a dynamic classification of users where the user data describes measured behavior not a category set beforehand. Artificial intelligence is used

in almost every aspect of user behavior adaptive systems: information presentations, user modeling, intelligent agent systems and user interfaces (Maybury & Wahlster 1998).

The Adaptive Geometry Game, presented in Chapter 5, is an example of an adaptive system that utilizes statistical decision-making rules. The rules control the game according to human-computer interaction during the game. The decision-making rules in the geometry game do not require background information about the learner. For that reason no learner profiles nor other pre-defined variables were used for user behavior adaptation implementation.

2) The client device adaptive systems deliver content for different types of platforms. Adaptation within these systems has been implemented with the utilization of environmental data. Though these sorts of adaptive systems are relatively easy to build, there are few studies and solutions that have been done in this area. There are for example Palm Pilot versions of different database interfaces (Billsus & al. 2000), but it seems that xTask (Ketamo & Multisilta 2001b) was one of the first platforms for adaptive learning and working. One of the most useful methods used in client device adaptive systems is the utilization of XML metadata. When content and functions are described with XML, the new devices or browsers only need a new style sheet for displaying the existing content. (Wehner & Lorz 2001).

The adaptation in this thesis is seen from both of these perspectives but it is studied mostly from the user point of view. The technology point of view in the platform adaptation is also important, but technologies change more quickly than the behavior of users. Therefore the focus on the platform adaptation studies is also on user behavior – behavior when working with different technological devices. User behavior is a more stable and reusable approach to adaptive learning systems. Because the focus of the thesis, this chapter is mostly about user behavior adaptation.

User modeling is based on facts about the user. These facts are analyzed, and according to rules constructed for the analysis, the users are grouped into different stereotypes (Rich 1998). The validity of Rich's modeling has many threats: 1) The facts do not have to be relevant to the issue and the facts can be presented more like an opinion than a fact. For example, a person can not evaluate himself with a high validity. 2) The rules constructed for analyzing are developed by people, and in most of the cases we can not be sure that the rules really are intelligent. 3) The stereotypes fit the learner into a category. However, constructive learning theories assume that learning styles can not be categorized, but learning is an active construction process.

Kinshuk and al. (2002) presents a classification of learning systems, varying from adaptable to adaptive ones. In this model the system is adaptable if a user can modify his or her settings in the environment. An adaptable system can also be a personalized system. It is said that the system is completely adaptive only if the system adapts to the user's behavior without any user data records. The systems between these extremes represent the whole scale of adaptive systems. For example, most adaptive systems are in the middle of the scale: They utilize user databases to evaluate the skill level of students. The problem within these user profiles stems from the time dependence of the behavior.

Intelligence in the state of the art solutions is based on neural, semantic, or Bayesian networks. Neural and semantic networks are utilized to model students' characteristics, learning profiles, patterns of behavior, and skill levels in order to support the performance of individuals (Kinshuk & al. 1998; Bollen & Heylighen 1996; Brusilovsky & Cooper 1999; Webb & al. 2001). Bayesian modeling is expected to provide more robust user profiles, though the profiles are still utilized as different classifications (Murray 1999; Nokelainen & al. 2001).

Mullier and al. (1999) describes an intelligent tutoring system which utilizes a pattern recognizer and semantic networks to model the expertise of students. Despite the computational diversity of systems, many of those are merely dynamic task trees (Carro & al. 1999a) with certain learning profiles (Kinshuk & al. 1999; Albrecht & al. 1999; Espinoza & Höök 1996; Brusilovsky & Pesin 1994; Hetherington & al. 2001). The learning profiles are seen as being too restrictive and limited to describe the real needs of a user. One of the biggest problems is in traditional expert-novice structures, which often only limit the linking and navigational support without bringing more versatile opportunities for differently skilled learners (Mullier 1996; Raskin 2000, 68-70).

Student modeling also has many obstacles: incomplete recorded information, uncertain observation situations, and non-stable user behavior. (Mullier & al. 1998; Albrecht & al. 1999; Arnes & al. 1998). In some adaptive systems these obstacles are avoided by allowing students to choose their own learning profiles (Carro & al. 1999b), but as mentioned before, those systems are mostly adaptable systems. There are also other obstacles to data labeling in complex environments. Even if data is labeled, the system should be taught to use collected data. On the other hand, conceptual models change quickly and it is not possible to react to the change immediately (Webb & al. 2001). McCarthy and al. (2001) describes an adaptive system, the behavior of which should have characteristics of a teacher's behavior. The system analyzes learners' records and teaches with the most suitable methods. In this solution there are two profiles which can not be modeled with available technology: the user and the teacher.

Navigational support is a major research area in the field of adaptive learning materials. It is clear that learning materials require a meaningful structure (McGee & Howard 1998). The navigational support is based on intelligent linking systems, represented by semantic or neural rules. Neumann and al. (2001) call the navigational support logistics. The logistics system recognizes the user and delivers only the content that the user needs. Navigational support can also be seen as an intelligent agent or a tutoring system (Prentzas & al. 2001) or more widely as human interface (Raskin 2000, 6).

Kinshuk and al. (1999) identifies six different linking types for intelligent navigational support:

1) Direct successor links represent the hierarchy of the learning material.
2) Parallel concept links represent the analogy between different learning objects.
3) Fine-grained unit links serve more detailed or deeper information of the domain.
4) Glossary links lead to a pop-up type external glossary area.
5) Excursion links offer information about a specific concept or represents the concept in a different context.
6) Problem links lead to the problems related to the current learning unit.

There are various linking agents which construct links dynamically according to a user's needs. Once again, the adaptation rules and student observation are the obstacles: There is no certainty that the adaptation rules and the recorded behavior describe the using processes. (Brusilovsky & al. 1996a). Also a fear about restrictive agents has been discussed (Dowling 2001). Because of the problematics, there are systems that just seek similar pages or remove visited links from the user interface by indexing recourses and learning paths (Aude 2000; Hasegawa & al. 2001). But the obstacles are not just in human behavior. If there are too many links, the cognitive overload is likely to cause confusion. A too narrow or non-systematic linking support may cause feelings of being lost within the material. Also finding a suitable skill level within linking systems may cause problems even though some user modeling system has been used. (Murray & al. 2000).

Several solutions that are not so dependent on these problems of human behavior modeling have been implemented. Brusilovsky and al. (1996b) describe an interesting approach for intelligent linking: First the concepts of the textbook are indexed. According to this index, the concepts can be presented in another context in order to support the knowledge constructing process. Soller and al. (2000) describe an agent that controls working in the environment with certain metadata. The idea of the system seems interesting, but the input of metadata should be developed so it is done automatically, because during real work a user does not like to answer several questions for every action.

As described before, navigational styles differ a lot. This can be seen as a risk for reliable learning profile modeling. Mullier (1996) describes five browsing strategies:

1) Scanning strategy, the aim of which is to cover a large area without depth.
2) Browsing strategy, in which a user just follows the links until he or she reaches a goal.
3) Searching strategy, in which user seeks the marks of the requested issue.
4) Exploring strategy, which can be seen as a developed form of scanning strategy.
5) Wandering, which represents the lack of strategy. Wandering can be seen as the least expected behavior on intelligent learning systems.

There are also other interesting approaches for adaptive navigational support. Jacob (1998) presents an interface which is controlled with eye movements. Eye movement measuring technology is widely in use, but there are many obstacles to building an eye controlled interface: Eyes move fast and there are many uncontrolled movements. Eyes also sometimes wander without focusing, and eye blinks are very random. This all may confuse the system and make the system unstable. Bolt (1998) introduces a user interface which can be controlled by physical movement, for example by moving oneself from one place to another. Though Bolt's interface works properly, it faces similar obstacles to the eye movement environment.

Chin (1998) approaches user interfaces in terms of intelligent agents. In his presentation an agent is seen as an individual object, and an intelligent user interface is constructed by different agents that try to adapt to the user's behavior. Chin assumes that an intelligent system must also be an active constructor of knowledge, but on the other hand he admits that this kind of an intelligent user interface could itself behave in an unexpected way.

3.2 Ecological validity in user behavior adaptation

The concept of ecological validity is used to describe how natural the test situations in experimental behavioral studies are. For example, observing a monkey in its natural environment is ecologically more valid than observing the monkey in a laboratory. According to Loomis and Blascovich (1999), the traditional relationship between experimental control and ecological validity of research is negative: when experimental control of research is high, the ecological validity is low, and in contrast, when the ecological validity of research is high, the experimental control is low (Figure 2). By using a virtual environment for the research and observation environment, both the ecological validity and experimental control of research can remain quite high. (Loomis & Blascovich 1999).

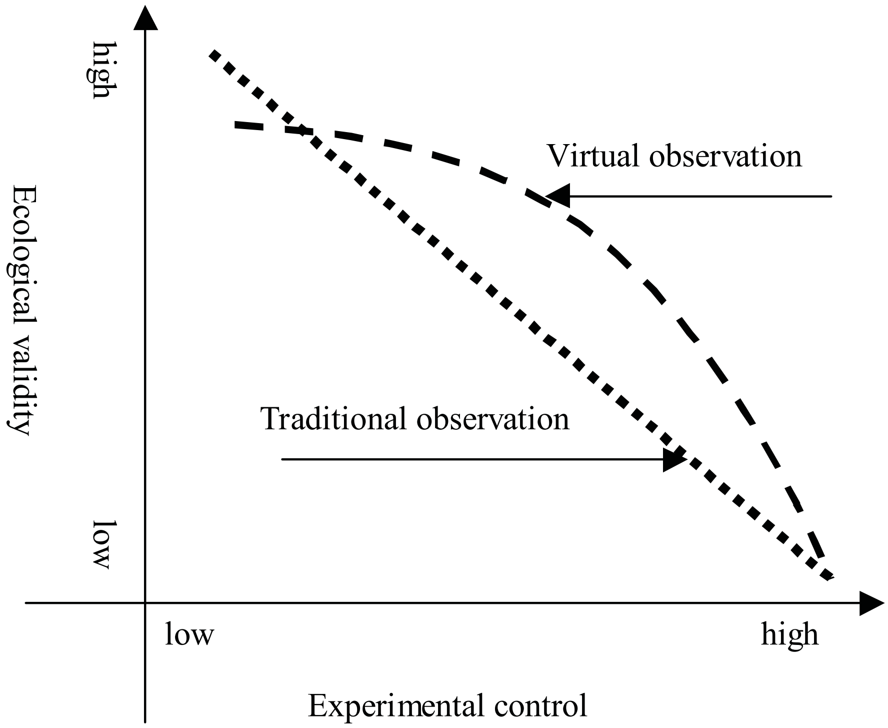


Figure 2. Ecological validity and experimental control according to Loomis and Blascovich (1999).

As shown in Figure 2, the amount of experimental control of virtual environment observation is quite close to the control in traditional observation when either ecological validity or experimental control is high. When using virtual environments in observation, experimental control decreases more slowly than in traditional observation environments.

This kind of ecologically valid observation systems is used in all studies described in this thesis. Though these environments are not 3D virtual environments, we can assume that hidden observation in Web-based learning materials can give more ecologically valid data using the material than traditional observation. When comparing this kind of virtual observation and traditional observation in quantitative research, we can not find any major differences in the quality of data. The most important and meaningful issue within testing is that we know what kind of information we want to have via the test. The implementation of the test should be based on these requirements of information. (Buchanan & Smith 1999a; Buchanan & Smith 1999b; Stanton 1998).

The adaptation system in the geometry game in Chapter 5 is based on observation that is invisible to the user. This is done in order to avoid set learning profiles beforehand and to ensure that the system can easily adapt to changes in the behavior of users.

3.3 Cognitive tools

The utilization of technology in teaching can be seen as a dimension which starts from information delivery and ends with cognitive tools (Reeves & Laffey 1999). In this classification a pure cognitive tool is an adaptive and intelligent agent, the only purpose of which is to support a learner's thinking processes. In reported studies cognitive tools are defined more widely: In fact many information delivery-oriented solutions are said to be cognitive tools.

The definition for cognitive tools in this study is the following: Cognitive tools support learner's cognitive processes in order to improve thinking, for example by organizing information with mind maps. (Jonassen & al. 1997; Pea 1994). The cognitive tool should cause reflection in which a learner is forced to evaluate his or her own conceptual structures and assimilate the new issue with existing conceptual structures (Jonassen 1994). Cognitive tools should be programmable or controllable in some way in order to support constructive concept mapping and reflection. Particularly the development of metacognitive skills should be supported with cognitive tools (Penner 2001; Kay 2001).

Lesgold (1998) has presented several dimensions for cognitive tools: 1) Level of cognitive functions, 2) presentation level, and 3) educational level.

1. The level of cognitive functions starts from skill-based functions, which are just skills of knowing how to behave in a certain situation. The next level is rule-based function, in which the learner can choose the behavior according to some known rules. The highest level is knowledge-based functions. At this level learner knows how to do some action and why.

2. The presentation level is a dimension between concrete presentation and abstract presentation. For example in geometry Fröbel’s blocks represent a concrete cognitive tool while Papert’s turtle geometry represents an abstract cognitive tool. (Riedesel & al. 1996)

3. The educational level can be seen as a dimension between education and training, where education is a holistic view of some issue and training focuses on well specified areas.

A subgroup of cognitive tools is electronic performance support systems (Reeves & Raven 2002). These tools are utilized to support knowledge work in groups and organizations. A cognitive tool can also be a method or an idea to support learning processes or knowledge creation, as the overall idea of a cognitive tool is to improve a learner's performance. The used learning context defines possible cognitive tools for learning. (Kennedy & McNaught 2001; Hokanson & Hooper 2000; Norman 1993). Ruokamo (2001) used a mathematical learning environment as a cognitive tool. This kind of method brings about positive attitudes towards mathematical problem solving and in that way improves learning results. According to Reeves (1996) claims that the whole World Wide Web can be seen as a cognitive tool in the context of knowledge creation, not in the context of information delivery.

Distributed cognitive tools (Giardina & Oubenaissa 2001) is a group of agents that can improve an individual’s thinking or group dynamics in learning or knowledge work. A discussion forum search engine for distributed forums can be seen as a simple cognitive tool for working groups. For more technological aspects, distributed cognitive tools can be seen as off-line agents, which exchange information when they find a connection to another off-line agent (Hong & al. 2001). These kinds of agents are also called, partly misleadingly, mobile agents. Mitsuhara and al. (2001) presents a distributed cognitive tool which collects distributed information with a linking system that takes into account some preferences of users.

In order to build better cognitive tools for small children, the rules and processes of specific learning tasks should be discovered (Miller 2000). The study on the Adaptive Geometry Game, presented in Chapter 5, describes a study which aimed at finding out these rules and finally, implementing and testing an adaptive and effective cognitive tool for small, approximately six year old, children.

4 PDA's and PC's as learning platforms

The aim of this study is to determine the differences in usage between PC's and PDA's for fulfilling the technical requirements of a good learning platform. This is done by studying the differences in interaction between PC and PDA environment and differences in reading speed between PC and PDA environment. Also the technical expertise and users' age are used as explanative variables for user behavior.

In this chapter the need for adaptive systems was approached from two perspectives: technology and user. The three different technology platforms, PC with mouse, PC with touch screen and PDA with touch screen, represented the technology perspective of the study. The tests measured the user behavior within different technology platforms from the pointing speed, recognition and readability points of view.

The results of this study were used in the following studies (in Chapter 5 and Chapter 6) as a background information and as models. The meaning of interaction was especially pointed out in Chapter 5 where the whole adaptation system was based on different dimensions of interaction. Readability is an important issue when building device adaptive systems even though the system can not adopt any text styles. The device should be used in teaching and training only if it can support meaningful reading opportunities.

The study about the use of the different terminals was done during the years 2001-2002 in co-operation with Ph.D Lauri Kemppinen (Ketamo & Kemppinen 2002). The planning of the measuring instrument as well as information collecting and the analysis of the results were done in co-operatively. The technological ideas and implementation of the measuring instrument rise from the previous research of the author (Ketamo & Suomala 2000; Ketamo & al. 2001a).

4.1 Research questions

User interface design and usability of the learning systems are important issues for optimizing learning results in web-based teaching and learning. The Web usability guides (Nielsen & Tahir 2002; Nielsen 1999) focus on business web sites. In business web sites the layout and easy access to most important products mean everything. Business web sites are constructed for busy readers or information seekers, who scan the information through without trying to learn anything (Mathieu & Schell 2001; Lazonder 2001).

The usability of business web sites can not be accepted as a departure point for learning materials. Therefore the recommendations of commercial web site design guides are utilized only when the recommendations can also be based on learning theories. There are also several models for evaluating learning materials. These models were not discussed here because they do not completely fit in the concept of adaptive learning systems.

The aim of this study is to determine the differences in usage between PC's and PDA's for fulfilling the requirements of a learning platform. Another, but not as important, aim is to point out the difficulties of virtual observation as a background for user behavior measuring. The model of suitable usage for the different platforms is examined through four questions.

1. What differences can be found in the speed of interaction between PC and PDA environment?
2. What differences can be found in the reading speed between PC and PDA environment?
3. What is the importance of the user's age for the usage of PC's and PDA's?
4. What is the importance of technical experiences for the usage of PC's and PDA's?

The information was gathered between June 2001 and November 2001. The tested sample was selected randomly from schools, colleges and universities of Satakunta region (in Finland). All tests were done in a controlled situation to provide equal opportunities for the whole sample. The number of the tested sample was 469, and the age of the participants was between 13 and 80.

4.2 Methods, tools and sample of the study

The methods and tools used within this study are described in this chapter. Also the limitations of the methods and tools used are discussed. The tests were slightly different between the PDA's and PC's. The PC tests were the first implemented tests and the PDA test was built afterwards.

When implementing the PDA test there were limitations within the PDA's browser JavaScript support: There could only be one active window. All the JavaScript commands and functions could not be used and the HTML was limited to Basic XHTML (W3C 2001). When analyzing the results this difference between the tests was recognized and taken into account.

4.2.1 Technologies of the study

The technology used in this study (laptop computers and PDA's with wireless network) was selected to represent future technologies in schools rather than the technologies of today. On the other hand, by using mobile technologies the laboratory equipment could be easily moved from one test school to another. There were three different types of platforms in this study (detailed distributions in Table 1):

1. Laptop computers, the screen size of which was 14" and resolution 1024 x 768 pixels. These PC's use a traditional mouse as the input device for testing. In the following text this platform is called PC 14".
2. Laptop computers the screen size of which was 9" and resolution 800 x 600 pixels. These PC's use touch screen as the input device for testing. In the following text this platform is called PC 9".
3. PDA's the screen size of which is 4" and resolution 240 x 320 pixels. PDA's use touch screen as the input device for testing. In the following text this platform is called PDA.

All the devices use at least 200Mhz processors and 11Mb/s ad-hoc (IEEE 802.11b) wireless networks. The server of the study was a laptop PC (750Mhz) which was also connected to same wireless network as the test devices. This kind of mobile laboratory was essential in order to collect such a big sample as almost 500 persons. The used technology seems to fit the purpose and there were no technical problems during the data collection.

Table 1. The distribution of users and devices.

	n	% of valid observations (missing data was excluded when calculating the percentages)
PC 14”	222	47,3
PC 9”	81	17,3
PDA	166	35,4

The PC 9” group was significantly smaller than the other groups. This means that the results of the PC 9” tests are not as reliable as the other results. Because of that, only significant results and general outlines of PC 9” are discussed here. Most analyses are based on the results of PDA’s and PC 14”.

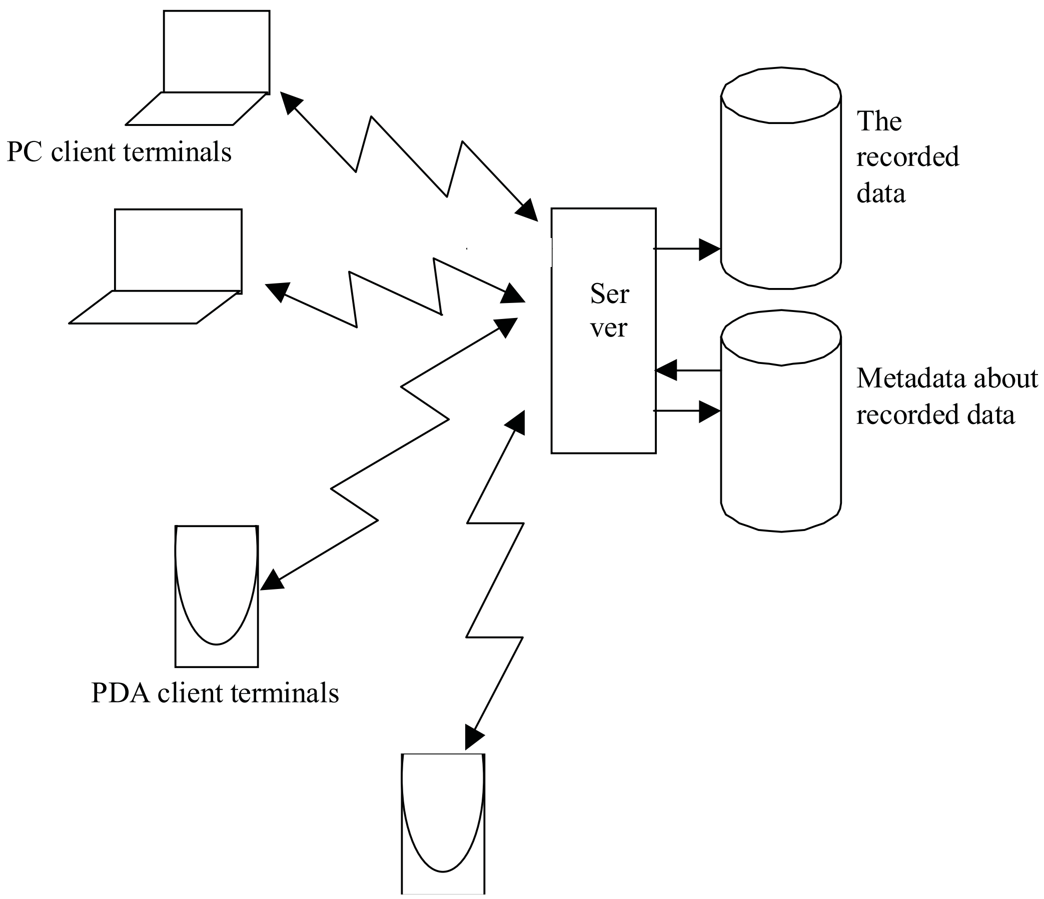


Figure 3. Illustration of the mobile laboratory of the study.

In Figure 3 the idea of the mobile laboratory is described. The server program includes three modules. The first module checks the client type and gives a questionnaire for background information implemented for the device. After the questionnaire is filled, the second module checks, according to meta information of the recorded data, the age and gender of the test person. All test data is stored locally until the test is finished. Then the client sends the data to the server and the third module records the data according to the session id. If the transfer succeeds the server sends an OK signal to the client. If the ok sign is not received in 15 seconds, the client tries to resend the information.

The server runs on an Apache web server, Perl programming interface and MySql database server. These were selected because of their performance capability and reliability. In addition, as they use free or open software, the test environment is reusable. The PC client programs were made with HTML and JavaScript and they run on Internet Explorer 4.0 compliant browsers. The PDA browser programs were made with XHTML Basic, which is a subset of XHTML (W3C 2001), and with a limited JavaScript.

4.2.2 Virtual measuring environment

The measuring environment was created especially for this study. It includes the following four stages:

A) Background information collecting with a multiple-choice questionnaire, including open questions (Appendix A, in Finnish, translated texts in English).

B) Pointing test, which measures the user's mouse speed or touch screen usage speed.

C) Recognition test, which measures the user's recognition speed when recognizing basic shapes, such as polygons.

D) Readability test, which measures the user's reading speed when the text is presented with different layouts (fonts, colors, etc.).

In stage A, the background information was collected with a WWW-form which was sent and analyzed on the web server. The direct data recording also saved a lot work when starting to analyze the results.

In stage B users were asked to point out black boxes as fast as possible. Only one black box was on display at a time. The pointing speed indicates only the speed of the hand when using the material. Pointing speed is an essential variable when studying the recognition speed. In the mouse test there were ten repeated tasks. One task included five variables:

Variable 1) Time for taking the mouse out of the current target.
Variable 2) Time for setting the mouse over a new target.
Variable 3) Clicking time in the new target.
Variable 4) The real length of the route that mouse moved from the old target to the new one.
Variable 5) The length of the shortest line from the old target to a new one.

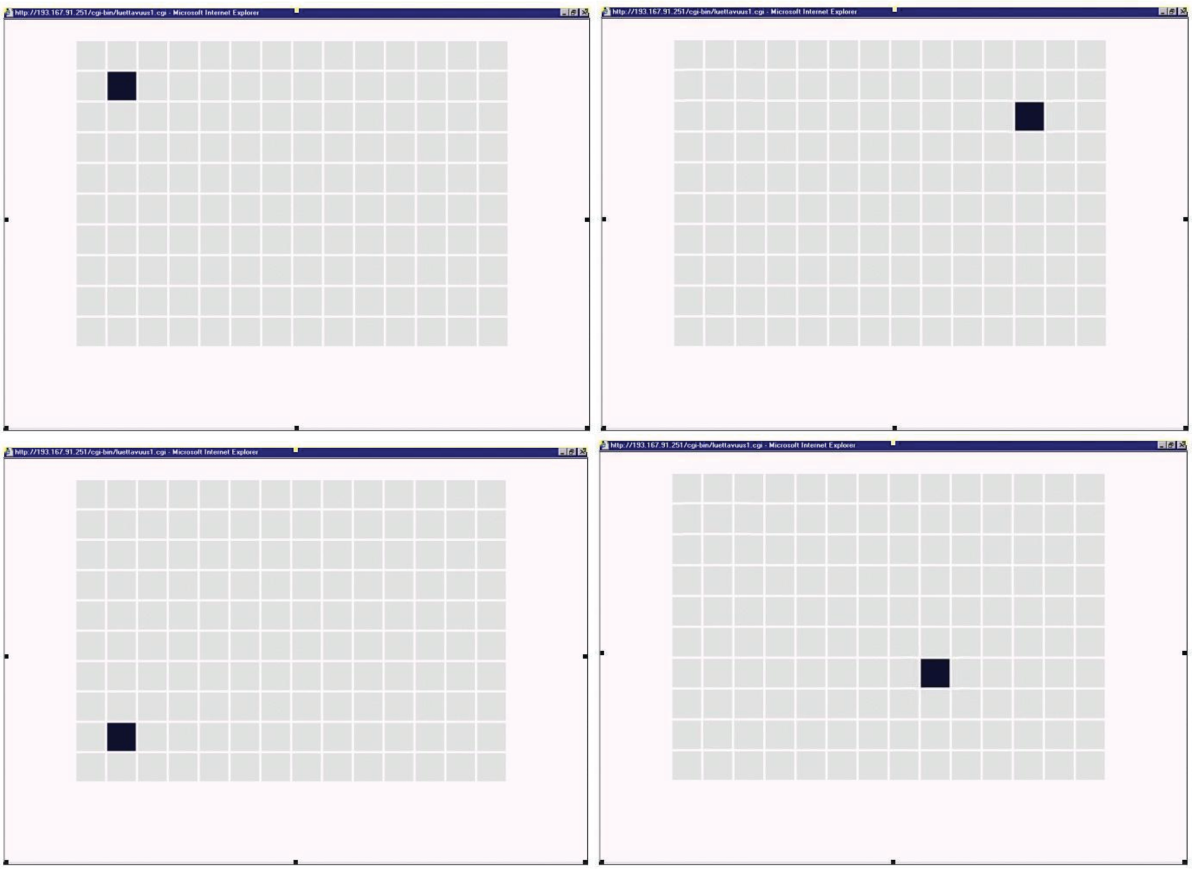


Figure 4. Four screenshots from the pointing test in PC environment.

Figure 4 displays the four first screens from the PC version of the test. The user was asked to point out a target (black box), which appeared into screen. When pointed at, the old target immediately changes its color to background color and the new target turns to black. Only one item in the screen was black at a time in order to minimize confusion during testing.

Hermina and Simon (1998) have used the same method but collected only the times between different events. This kind of data collection gives us more information about the use of the mouse. Unfortunately mouse out, mouse over, and real length of the route can not be recorded in PDA and touch screen displays, as there were no sensors for that.

Raskin (2000, 72) describes a keystroke-level model (GOMS) for user interaction observation and analyzing. The method used in this study is quite similar to Raskin's model. Another useful user interface research theory is Fitts' law (Raskin 2000, 93). Fitts' law is utilized in the analysis of the results. Fitts' law describes the average usage speed of the graphical interface as a linear representation (Figure 5). Time

$$t = a + b \log_2(d/s+1)$$

where **a** and **b** are constants, **d** is the distance between the starting point and target and **s** is the size of a target.

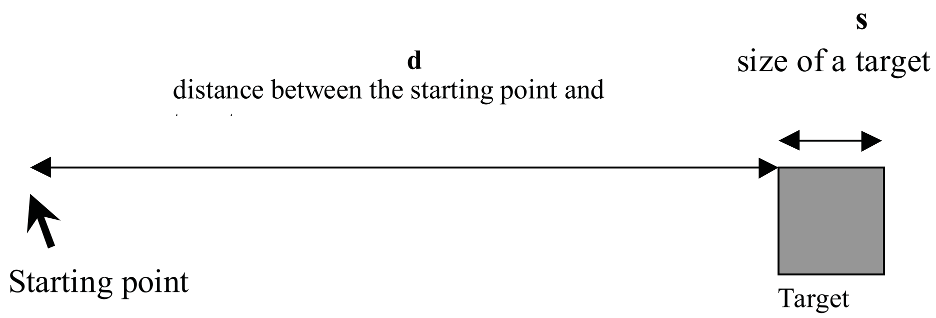


Figure 5. Fitts' law.

The reliability of the mouse test was estimated through the correlation between the tasks. The first task did not correlate to others as strongly as the other tasks did, which indicates that there was some confusion at the beginning of the test. Therefore the first task was not taken into account for the analysis.

The rest of the tasks correlate to one another strongly ($0,141 < r < 0,629$ $0,002 < p < 0,000$), which means that statistically, the tasks measured similar phenomena. This result also indicates that learning during the test was quite similar for all the people tested. In the analysis the sum of all the variables

$$v_{sum} = v_2 + \ldots + v_{10}$$ (v marks variables 1-5 from the list, page 31)

of all the tasks were used to improve the reliability of the measurements. Only the first measurements were excluded because of several mistakes by users within the first operation.

In stage C of the PC version of the recognition test there were 36 polygons, from which four represented a triangle (Figure 6). Each test person was given the task of finding all the triangles as fast as possible. The polygons were familiar shapes for all the people tested (aged over 13) and therefore the test measured recognizing not thinking, though low level thinking operations were used during the PC version of the test.

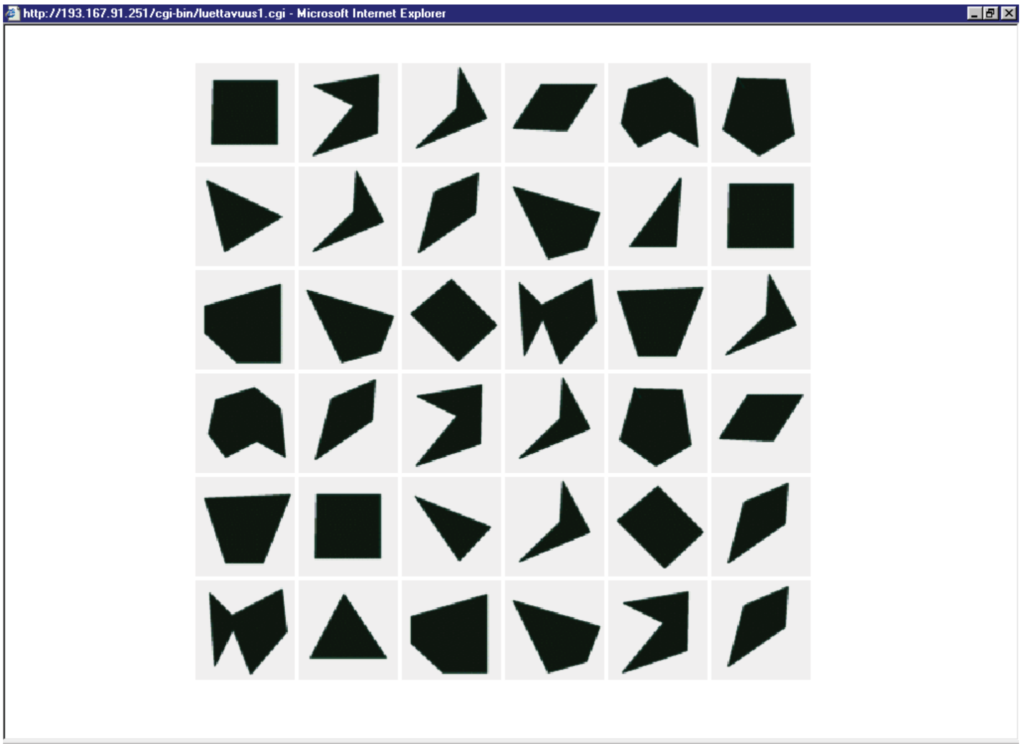


Figure 6. The layout of the PC version of the recognizing test.

The PDA version of the test also included 36 shapes, but in this test 32 shapes were squares and four of them were circles (Figure 7). The tested persons were asked to find out the circles as fast as possible. The recognizing of the circle and square is such a primary operation, that the tested time within this test was quite the same as the tested time in the mouse test. The easier test for PDA's were implemented because of the limitations of the scripting language in PDA environment that made changing shapes difficult to implement. Unfortunately the tests were so different that the results in PC and PDA tests could not be compared to each other.

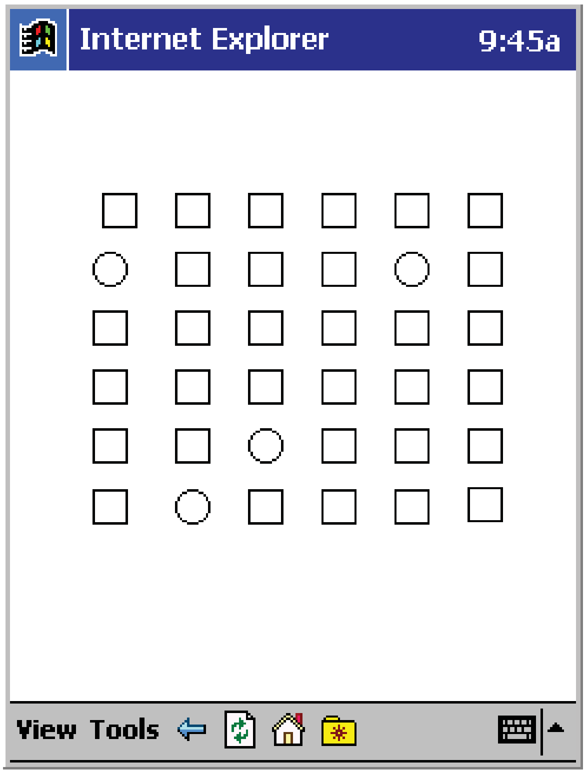


Figure 7. The layout of the PDA version of the recognition test.

These tasks were repeated twice. The measured variables were clicking times, the number of mistakes and in the PC version the real length (cm) of the mouse move. When calculating the correlation between the clicking time variables in repeated tasks we can find out that they measured exactly the same phenomenon. All correlations were statistically significant ($0{,}249 < r < 0{,}467$ $p=0{,}000$) which shows quite a high reliability. Only the last tasks were used in the analysis to ensure that confusion that occurred with a few persons in the first test would be excluded.

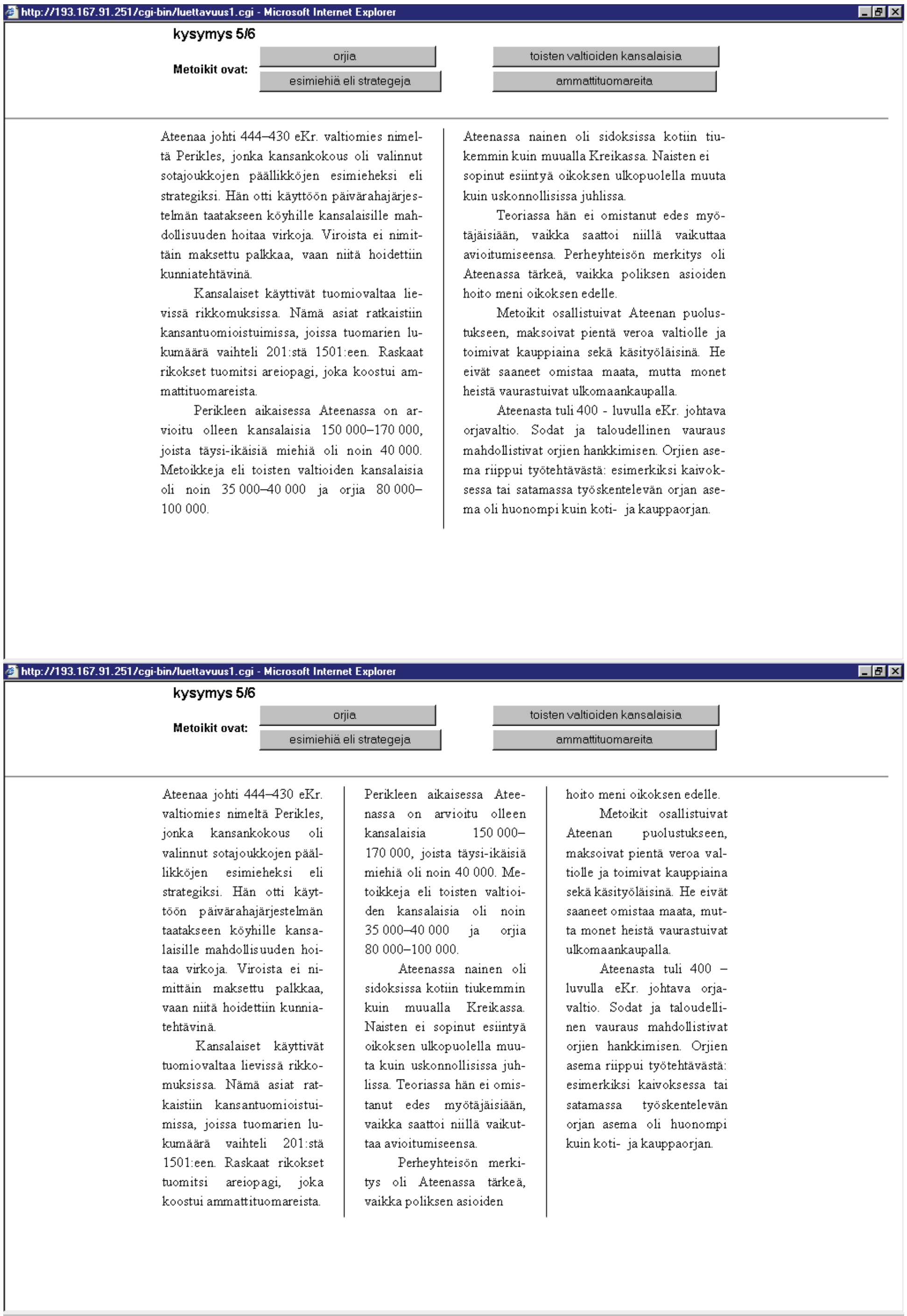


Figure 8. Two layouts of the PC readability test in the 'number of the columns' task. The third layout was constructed with one column.

In stage D, the readability test requires at least scanning reading style. The original idea of the readability test was to determine the best layout of digital learning materials for different platforms in order to support text readability. There were six tasks in this test. All tasks included three slightly different layouts. The layouts differed only on one variable in one task (Figures 8 and 9). The observed variables were:

Variable 1) Font type
Variable 2) Font size
Variable 3) Font colour
Variable 4) Column width
Variable 5) Number of columns (Figure 8)
Variable 6) Line spacing

Figure 9. Two layouts of the PDA readability test in font size task. One layout was 12pt font between these 10pt and 14pt fonts.

The texts were college-level history and the text included such fine details that it was not possible to know all the answers before the text was read. The answering was done by selecting an item from a list of answers at the top of the page. If the answer was right the next task appeared; otherwise the old task remained.

The information efficiency theory (Raskin 2000, 84) explains theoretically the same results as those obtained in this reading test. If the information is presented in its minimal form and does not contain other elements, the requested information can be found in less time than the requested information among other information. Though the theory itself is interesting it is not useful within all learning materials: Simplified information is not always the most efficient way to teach. Therefore it is not discussed within the analysis of the readability test's results.

4.2.3 Sample of the study

The gender distribution was statistically quite equal within all platforms. The sample included mostly young people (Table 2), and they were distributed not so equally into each platform as expected (Table 3). In the server there was an agent that handled all the collected background information, and according to key elements, gender and age, the program decided which kind of testing set was displayed for the tested people.

The agent could not affect the selection of platforms among the test people, and that was due to the uneven distribution of the usage of platforms. The PC 9" especially can be analyzed only in the under 20 year age groups and between 36 and 50 years of age. The age group over 66 years can not be discussed, as there is only one tested person in this age group.

Table 2. The age distribution of the study.

	n	% of valid
12-15 years	187	40
16-20 years	110	23
21-35 years	112	24
36-50 years	37	8
51-65 years	22	5
over 66 years	1	0

Table 3. The age distribution in different platforms.

	PC 14"	PC 9"	PDA
12-15 years	32%	24%	44%
16-20 years	36%	25%	39%
21-35 years	78%	1%	21%
36-50 years	65%	16%	19%
51-65 years	46%	9%	45%

When examining average experiences in computer use, an interesting issue can be seen. In general, almost all age groups have used the computer for approximately four years (Table 4). This reflects the fact that most Finnish homes bought their first home computer between the years 1996-1998. Naturally there are people who have had a computer at work for 20 years and people who do not have much experience with computers before this test. The increase of home computers in the late 90's as well as increased computer utilization at work and in education explains this quite well (Tilastokeskus 2001, 145-148).

Not surprisingly, males (user experience 4,4 years on average) as a group have used computers statistically significantly (t=-3,429, p=0,000) more than females (user experience 4,0 years on average).

Table 4. Distributions of computer experience.

	Experience in computer use (years in average)			n
12-15 years	4,0			187
16-20 years	4,1			110
21-35 years	4,4			112
36-50 years	4,5			37
51-65 years	4,0			22
		female	male	
all	4,1	4,0	4,4	t=-3,429, p=0,000

The question about how often people use computers gives us quite similar results (Table 5). It is interesting that the computer using experience is the biggest in the over 50 year age group, but this can be explained by the nature of their work. The use in under 15 year age group includes a lot of gaming, especially with males.

Table 5. The distribution of the amount of computer use (those who do not use computers in their work or free time are excluded in the table).

	Daily	Several times per week	Few times per week	occasionally
12-15 years	30%	14%	32%	22%
16-20 years	18%	25%	26%	30%
21-35 years	31%	24%	31%	13%
36-50 years	51%	21%	13%	11%
51-65 years	55%	9%	14%	14%

As for the amount of computer use, males were more active than females. When males in average were represented by the ‘several times per week’ user group, females were on the average represented by a ‘few times per week’ group. There was a high statistical significance with this result (t= 8,963, p=0,000).

4.3 Results of usability study

4.3.1 Pointing test

The results of the pointing test according to the platforms are presented in Table 6. The PDA platform was significantly faster to use than the PC with a mouse (t= 2,210, p=0,028) or PC with a touch screen (t=2,540, p=0,012). This result relies on the size of PDA screen, which is quite optimal to look at without any eye movements. Also the distances between elements on the screen are smaller and according to Fitts’ law (Raskin 2000), the speed of the action is higher. The touch screen system itself did not create the effect. This can be proved by a comparison between the two PC’s. In comparison, no statistical significance was found.

Table 6. The pointing test results according to the platforms.

	Clicking time in average (sec.)
PC 14”	1,57
PC 9”	1,70
PDA	1,45

When the pointing speed is examined over age groups (Table 7) the relationship between age and use speed can be seen clearly. Statistical significance can be found with non-linear correlation which was calculated between the age group and clicking times. Each correlation can be seen after the age group’s results. When moving from a younger age group to an older age group the speed between two clicks increased.

The mouse over time, delay time and real length of the mouse movement could be recorded only for the PC 14”. These values can be seen from the Table 8. The same kind of phenomenon as with the clicking times, appeared with the mouse over and delay times: The young users got better results with high statistical significance. Within these tests, the under 35 years age group managed better than the older group (p=0,002**). In fact the same age divides the population with clicking times, but the differences are not so clear. An interesting thing is that the fastest age group were the under 15 years olds (p=0,024*). This might be explained by their experiences in playing computer games, which often requires a fast mouse hand.

Table 7. Pointing speed according to age groups.

Platform	Age group	Average pointing time (sec.)	n
PC 14”	12-15 years	1,42	60
	16-20 years	1,54	40
	21-35 years	1,55	88
	36-50 years	1,84	24
	51-65 years	2,23	10
		r=0,373 p=0,000***	
PC 9”	12-15 years	1,57	45
	16-20 years	1,57	27
	21-35 years	1,76	1
	36-50 years	3,07	6
	51-65 years	2,10	2
		r=0,370 p=0,000***	
PDA	12-15 years	1,35	82
	16-20 years	1,33	43
	21-35 years	1,65	23
	36-50 years	1,39	7
	51-65 years	2,38	10
		r=0,313 p=0,000***	

Table 8. Other pointing speed indicators.

	Mouse over (sec)	Delay (sec)	Real length (cm)	n
12-15 years	0,95	,46	14,1	60
16-20 years	1,05	,49	13,9	39
21-35 years	1,05	,48	14,0	88
36-50 years	1,15	,68	14,2	24
51-65 years	1,43	,87	15,0	9
	r=0,354 p=0,000***	r=0,278 p=0,000***	r=0,049 p=0,470	

The real length of the mouse move was quite similar in all age groups and no statistical differences were found. Consequently, the age does not affect to the mouse skills. Though the movement is slower, the movement is stable.

The differences in use speed between genders were also examined. When using the traditional mouse, males were significantly faster than females (Table 9). Within the other platforms this kind of phenomenon did not exist, the use times were quite similar.

Table 9. The differences in pointing speed between males and females.

	Women (sec)	Men (sec)	t-value	df	p
PC 14”	1,66	1,46	3,447	220	,000***
PC 9”	1,77	1,62	,847	79	,399
PDA	1,49	1,42	,697	164	,486

Long user experience in computers improves the use speed within traditional mouse platforms and within a PDA platform (Table 10). The results within these platforms are clear. In the PC 9” platform user experience was not found to be an explanation for use speed. The results with a PC 9” platform might be explained by the familiar environment which the test people were asked to control a non-familiar system (touch screen). This might have confused the tested people and thereby affect the results.

An interesting phenomenon which can be seen from Table 10 is that the test persons, who had less than one year experience in computers, used the mouse more slowly than those who had more experience in computers. This result can be seen within the PC 14” and PDA platforms. In addition, those who had over ten years experiences in computers used the mouse more slowly than those with 1-10 years experience. These persons with over ten years of computer experience were slightly older people who used a mouse more slowly than younger persons. The fastest mouse users, aged 13-20, had 1-10 years in computer experience and those age groups got the best results as shown in this table.

Table 10. User experience and the pointing speed.

		Pointing speed (sec)	n
PC 14”	no experience	1,70	6
	0-6 month	2,31	7
	6-12 month	1,76	9
	1-2 years	1,52	25
	2-5 years	1,55	79
	5-10 years	1,48	74
	over 10 years	1,68	22
		r=-0,185 p=0,006**	
PC 9”	no experience	1,61	4
	0-6 month	2,78	1
	6-12 month	2,05	2
	1-2 years	1,54	10
	2-5 years	1,69	32
	5-10 years	1,68	27
	over 10 years	1,85	5
		r=-0,007 p=0,950	
PDA	no experience	2,02	4
	0-6 month	2,47	3
	6-12 month	1,80	5
	1-2 years	1,39	19
	2-5 years	1,43	68
	5-10 years	1,37	44
	over 10 years	1,42	23
		r=-0,190 p=0,015*	

When discussing the amount of the computer use, those who used computers every day managed well with the traditional mouse platform (Table 11). In the other platforms, the amount of the computer use showed no effect. Once again, the touch screen PC may have confused some people tested and so the familiar mouse platform benefits from this kind of behavioral conflict. Especially, it seems that those who use computers often were confused as they got rather poor results from the pointing speed in the touch screens.

Table 11. The amount/frequency of computer use and use speed.

	Nature of computer use	Speed (sec)	n
PC 14”	Uses computers daily	1,46	60
	Several times per week	1,56	49
	A few times per week	1,56	72
	Occasionally	1,79	40
	Does not use	1,57	1
		r=0,226 p=0,000***	
PC 9”	Uses computers daily	1,88	24
	Several times per week	1,52	14
	A few times per week	1,63	18
	Occasionally	1,71	22
	Does not use	1,42	3
		r=-,090920 p=0,419	
PDA	Uses computers daily	1,47	59
	Several times per week	1,30	28
	A few times per week	1,43	43
	Occasionally	1,50	34
	Does not use	2,54	2
		r=0,059 p=0,453	

This phenomenon with easily operated PDA platforms can be compared to mobile phone use (Ketamo & Multisilta 2001a, 34-36), which was so simple that it is not necessary to train the technical use of the device. Naturally we have to remember that within a PDA environment the long-term experience of computer use indicates the use speed. This could be explained by the similar metaphors within the platforms.

4.3.2 Recognizing test

In the recognition test the users were asked to point out four triangles out of 36 shapes. In Table 12 the average finishing times (all four shapes pointed out) are presented. In the PC platforms the test persons reached almost the same average times in recognition. In contrast, in the PDA platform the test people reached remarkably better average times than in PC environments. This depends on a slightly different and a lot easier test: In the PC environments the shapes were polygons and only triangles were required to be pointed out. In the PDA environment the shapes were squares and circles among which the circles were required to be pointed out. These tests measured different levels of recognition. While recognizing circles from the squares was almost a reflex, recognizing different polygons required thinking. The polygons were just any kind of polygons, not only the prototypes of triangles (all sides have the same length) along with other polygons.

Table 12. The finishing times in the recognition test in different platforms.

	Average finishing time (s)
PC 14”	18,65
PC 9”	18,66
PDA	6,51

The separate test for the PDA was implemented because of the limited scripting language support in PDA’s web browser.

When comparing the correlation between the recognition test times and the pointing test times (Table 13) we can prove that the PDA test measures different phenomenon than the PC test. The PC recognition test in both PC environments is not related to the PC pointing speed test. This means that these tests measured different phenomena. However, the PDA recognition test correlates with the PDA pointing test with high significance. This means that these tests measured the same phenomenon.

Table 13. The correlation between interaction and recognition tests.

		time (sec)	r	p
PC 14”	pointing speed	1,57		
	recognizing	18,65	,102	,128
PC 9”	pointing speed	1,70		
	recognizing	18,66	,036	,750
PDA	pointing speed	1,45		
	recognizing	6,51	,296	,000***

The recognition test is discussed mostly according to the PC 14” results as this group was the only reliable group within this test. Age, once again, seems to have an important role within the recognition test. Now the situation is opposite to the one in the pointing speed test: The older users managed the recognition test significantly faster than the young people (Table 14).

In this test the real movement of the mouse was dependent on age. The older users did not wander around with the mouse and therefore accomplished the task with less movement. Both results indicate that the older users thought more during the tests and therefore got worse speed results but better results within tasks requiring mental activity.

Table 14. Recognizing test results in age groups.

		Real length of mouse move (cm)	Finishing time (sec)	n
PC 14”	12-15 years	62,5	22,90	60
	16-20 years	54,9	20,04	40
	21-35 years	40,5	15,27	88
	36-50 years	40,2	16,00	24
	51-65 years	51,2	23,77	10
		r=-0,148 p=0,027*	r=-0,209 p=0,002**	
PC 9”	12-15 years		16,60	45
	16-20 years		20,73	27
	21-35 years		13,02	1
	36-50 years		24,87	6
	51-65 years		21,34	2
			r=0,205 p=0,066	
PDA	12-15 years		5,52	82
	16-20 years		5,67	43
	21-35 years		5,96	23
	36-50 years		5,71	7
	51-65 years		19,83	10
			r=0,255 p=0,000***	

In the PDA version of the test the results were similar to the pointing speed test. The younger users finished the test faster than the older users, but as mentioned before, the PDA test was almost the same as the pointing test and it measured only the speed of movement not real recognition.

In the recognition test long-term experience with computers explains the results even more significantly than age. Those who have long-term experience with computers moved the mouse significantly less than those with less experience in computers (Table 15). Also the finishing times of the recognizing task were significantly smaller within the experienced groups than with the less experienced groups.

Table 15. The results of the recognition test categorized by long term experiences with computers.

		Real length of mouse move (cm)	Finishing time (sec)	n
PC 14"	no experience	100,5	41,14	6
	0-6 month	42,3	20,11	7
	6-12 month	46,2	19,60	9
	1-2 years	65,7	23,41	25
	2-5 years	45,7	17,06	79
	5-10 years	47,1	17,36	74
	over 10 years	42,5	16,31	22
		r=-0,221 p=0,000***	r=-0,175 p=0,009**	
PC 9"	no experience	-	16,08	4
	0-6 month	-	22,19	1
	6-12 month	-	27,52	2
	1-2 years	-	19,32	10
	2-5 years	-	16,77	32
	5-10 years	-	20,32	27
	over 10 years	-	18,33	5
			r=0,026 p=0,814	
PDA	no experience	-	36,85	4
	0-6 month	-	6,00	3
	6-12 month	-	5,20	5
	1-2 years	-	5,53	19
	2-5 years	-	5,63	68
	5-10 years	-	5,98	44
	over 10 years	-	6,04	23
			r=-0,259 p=0,000***	

By adding these two last results, we can say that age and long-term experience with computers supports recognition operations within digital environments. This result is essential in order to model rules for adaptive user management systems. This result also points out the problems within user profiling: Profile agents should be able to recognize this kind of user operation in order to rank the learner and his performance in a reliable way.

In the PDA version of the test the people with 1-2 years experience obtained the best results. This group includes most of those young people who also managed well in the pointing speed test.

Short-term use of the computer does not explain anything about the recognition issue. This is no wonder when summing up the previously mentioned results about the expertise of older users within digital environments recognition. Recognition does not depend on gender. Neither correlations nor differences were found between the genders.

4.3.3 Readability test

The readability test focused on comparing the different platforms in order to provide a good environment for text-based learning material. Only three tasks out of six can be used within the analysis. The paragraph tasks and line spacing task were not implemented in PDA's because of the limited scripting support and the sometimes unexpected display of graphics in the PDA.

Also background variables, such as age and long-term experience in computer use, are examined in order to provide a wider perspective for learning materials readability. Unfortunately only a few direct layout construction tips were found concerning the fonts or page layout. Naturally, the contrast of colours used, as well as other factors like that should be taken into consideration when constructing learning materials.

The differences between platforms are discussed only with PC 14" and PDA platforms. The PC 9" platform is excluded because in the previous mentioned tasks there were a lot of confusion within the use process. It seems that comparing the PC 9" environment to the others would not be reliable, because there were other uncontrolled features within the use process.

In Table 16 the results from the three tasks are compared between PC 14" platforms and PDA platforms. According to the results we can say that the PC 14" platform was significantly better than the PDA platform for supporting learning materials readability. The results give clear evidence for that, especially because the different layouts or tasks did not affect the result in any way.

There was one obstacle in these readability tasks, which was discovered when doing the analyses: The text presented in the PC 14" environment fits the screen, but the same texts presented in the PDA environment needed to be scrolled. Probably the scrolling system is one of the obstacles leading to poor results in the PDA environment. Maybe a more book-like metaphor, like turning pages (used in MS-Reader for PDA's), would have given better results. Therefore in the future it is important to find out if the results of the readability test would be higher with a reader-type of environment.

Table 16. Differences in readability between PC 14" and PDA environments.

	PC 14" time (sec) n=222	PDA time (sec) n=166	t-value	df	p
Font type	49,78	62,57	-2,924	268	,003**
Font size	21,86	37,57	-6,529	268	,000***
Font colour	31,42	49,08	-6,171	268	,000***

The only layout tip for the PDA environment was found within font sizes. Font sizes that are too big are slower to read than smaller ones (Tables 17-19). In this study the 14pt font seems to be too large for the PDA screen when comparing it to the 10pt font (Table 17), but no statistical evidence was found when comparing the 14pt font to the 12pt font (Table 19).

The slowness of use is probably due to the effect of scrolling: When the font size grows, the user must scroll the text even more in order to find the information he needs. It is obvious that small fonts also make the text hard to read. In this task the 10pt font was readable, but still some older people said that it was difficult to read, because it was too small.

Table 17. Differences between 10pt and 12pt font readability in the PDA environment.

10pt time (sec)	12pt time (sec)	t-value	df	p
32,38	35,33	-,487	73	,627

Table 18. Differences between 10pt and 14pt font readability in PDA environment.

10pt time (sec)	14pt time (sec)	t-value	df	p
32,38	44,00	-2,048	81	,044*

Table 19. Differences between 12pt and 14pt font readability in PDA environment.

12pt time (sec)	14pt time (sec)	t-value	df	p
35,33	44,00	-1,397	78	,166

Information seeking (Lazonder 2001) is said to be the main way of using the web. To help the seeking process there should be minimal guidance and only the most important text presented. According to Lazonder, the information seeking process develops only by training. When comparing the effect of age to the result of the readability test, the older people as a group were significantly better than the younger people (r=-0,181, p= 0,001**). This can be seen by comparing different groups to one another or by looking at the correlation between the age group and test results. The same results can be seen within all platforms and all different layouts in some form, but naturally the effect is not as strong in all the separate combinations. This indicates that Lazonder's suggestions about scanning reading style development were right.

In all tasks the worst group was the one composed of 13-15 years olds. This indicates that they are behaving impulsively in digital environments and therefore text-based learning materials are not the best solution for them. This assumption gets more evidence when comparing the recorded mistakes during the test. When the correlation between the number of mistakes and the age group was calculated, a strong relation between young age and a big number of mistakes was found (r=-0,191, p=0,000***). Accordingly, we can be sure that text based digital learning materials have a risk of failing with young pupils if they are presented without any controlling or feedback system.

4.4 Digital behavior, readability and adaptive systems

In this chapter the results of the study are discussed from two perspectives: The most important empirical results from the behavior adaptation point of view are discussed Chapter 4.4.1. The most important empirical results in the terms of platform adaptation are discussed in Chapter 4.4.2.

4.4.1 Results in the terms of behavior adaptation

In general, the results of the study can be discussed in many contexts. When discussing the user's preferences that affect the using process, impulsive behavior is one of the most interesting issues. The males aged less than 20 years use the mouse more effectively than the other groups. On the touch screen platforms (PDA and PC 9") there was a similar phenomenon. Only in these platforms did the females manage as well as the males within all the age groups. Computer games, for example, might have influenced the pointing speed of the group of males under 20 years. This can be assumed according to details of earlier experience and the amount of the computer use.

According to the results, to support interaction between user and computer, the system should notify the interaction speed in the user interface. This can be programmed by observing the interaction speed when using the system. According to the pointing speed, the system could change the size of the icons in the user interface. For fast users the icons could be smaller and for slow users the icons can be larger.

The idea about giving different sized user interface icons for differently skilled users is based on Fitts' law (Raskin 2000). It can be applied directly into an adaptive system when the constants in the formula have been studied for the user interface. According to Fitts' law the time to target can be shortened by enlarging the size of the target.

This kind of optimizing reflects the expert - novice classification, but because it is based on observed information it can not be seen as given classification. This classification mechanism allows fast changes in the user profile. The age-based user profiles for user interface optimizing can not be recommended according to theories: In Chapter 3.1 we found out that the user profiles that are based on given information are seen too restrictive for powerful adaptation.

In addition to age and expert-novice classifications, pointing speed can also discussed in the terms of reflective-impulsive classification. A reflective user spends more time before pointing at a target than an impulsive user. This is because the reflective user wants to carefully check all the possibilities before performing actions. Impulsive users do not think as much as the reflective user and therefore the impulsive user is faster in actions. From an adaptive system point of view the impulsive users are more challenging: The system should somehow be able to guide impulsive users despite, or just because of, their fast interaction.

In the readability test the young users (according to their age) made more mistakes than the older users. The older users also accomplished the tasks faster than the younger ones. This can be explained by changes in behavior when people grow: Young people behave impulsively in digital environments, but after some time they learn to think reflectively and in consequence, start to behave in a reflective way in digital environments. What is more, the impulsive behavior of young people transfers into reading styles and results in poor reading of digital texts. After some years, when more reflective behavior in digital environments has developed, the reading style will improve. The importance of so-called scanning reading style is concrete within today's economy.

The use of scanning reading style rises from achieving competitive benefit in business (Ahituv & al. 1997). In commercial web sites redundant information should be avoided (Nielsen & Tahir 2002, 14), but according to the Dual Coding Theory (Paivio 1991) redundant information improves learning. This paradox shows us that most commercial usability guides can not be adapted to the design of learning materials as they are today. In the Chapter 4.1 the problem within the usability of learning materials was discussed in many contexts, but business web sites are referenced only if some empirical or theoretical evidence for their suggestions in the context of learning can be found there.

The problem with commercial guides does not mean that business web site guides should be avoided as a whole when building learning materials. Business web site guides can be used within certain issues. For example, Nielsen's (1999, 180) ideas about using metaphors or Fleming's (1998, 13-14) navigation guidelines, as well as general usability heuristics, are worth reading when planning the layout of the learning system.

The paradox within reading style development leads us into an uncertain situation: One need for adaptive learning systems rises from an inefficient reading style and impulsive acting in digital environments, but both will improve with time. The question is: how to support more effective reading styles by adaptive learning materials without harming the natural development of this kind of skills. There are risks that, by supporting learning by adaptive methods, we at the same time destroy the natural development of some other skills.

In the following Chapter 5 impulsive and reflective behavior are examined as key factors of the behavior adaptive cognitive tool. The dimension between impulsive and reflective behavior is approached through 1) speed of interaction, and 2) relative number of mistakes. These dimensions give good results for finding out the rules of effective learning materials. Reading styles are not discussed in the following chapter, because the test groups were six year old pupils and reading was not developed or even a related subject.

4.4.2 Results in the terms of platform adaptation

When comparing the different technology platforms, the most obvious result is that PDA’s can be used quickly. In spite of the experience of playing computer games, only a few of the PC 14” users reached the average PDA pointing speed. It is also remarkable that none of the PDA test people had used PDA’s before the test. The PDA test group was familiarized with the PDA only a few minutes before the pointing speed test. This indicates a good usability of touch screen within the small devices.

This result indicates that the vision of an adaptive user interface discussed in the previous chapter (4.4.1) is most important for PC environments. Even though there were differences in the speed of interaction between users, the results were not as clear in the PDA environment. This indicates that adaptation rules or limits would be more difficult to find for PDA’s than for PC’s.

The PC 9” which had a larger touch screen than PDA’s was not as fast to use as PDA’s. This indicates that the touch screen can be fast only when hand movement is limited and the user can see the whole screen without moving his/her eyes. The hand-eye combination seems challenging for platform adaptation: how to minimize hand movement for touch screens without losing the usability of the mouse pointing systems in order to support both mouse and touch screen?

Because of that, the platform adaptive system can not be adaptive only for the platform: It should also be adaptive for different input devices. The adaptive interface for the PC 9” in this study should be quite similar to a PDA’s interface: The icons that are for user interaction should have approximately same size as in the PDA’s interface because movement of the hand should not be enlarged. The rest of the screen can be used as in those PC’s where the mouse is the input device. This indicates that the interface design should be different for platforms that are using a mouse as a pointing system than for platforms using touch screen as a pointing system.

Especially we should point out that traditional Web navigation is not optimal for touch screens: In traditional Web navigation there are navigation buttons at the top of the page and on one or both sides of the page. This kind of navigating system requires a lot of movement for input device and according to results, too large movement slows down the speed of interaction.

Readability in the PDA platforms was poor. This could be due to the text scrolling system of the test which was not optimal for reading. It is possible that some kind of page turning mechanism would have been better for the PDA test. Readability was poor also because of the fact that the screen resolution of the PDA device was not sharp enough to be presented in 8pt or smaller fonts. This led to a situation in which the information could not be presented effectively on the screen: When comparing the character size to the distance of the screen and user's eyes the characters were too large and the column was not optimal for reading.

This reading point of view is interesting especially for the PDA environments: When the text can be presented in PC's screen as it has been presented before, it should be modified for PDA's screen. This modification will not be technologically difficult to implement. The challenge is to find out the best possible way of presenting text in PDA's. In reader programs, the text has been divided into pages which can be turned as in books. This works well, but we can assume that there are several styles in using text for different users and therefore platform adaptation only is not enough for texts.

Another issue in text adaptation is font size, which should be changeable. For the font the adaptation is not the only choice: Maybe an adaptable system in which the users can optimize the font size for themselves would be better than adaptive systems which try to define the optimal font size. For example in MS Reader (for PC and PDA environment) the user can change the font size from the settings menu. According to empirical results of the study, this seems a good feature, especially for PDA's.

In the Chapter 6 the results of user behavior in different technological platforms are utilized in a description of adaptive groupwork environment, xTask. The results are also utilized when analyzing the behavior of users in the xTask environment.

5 Adaptive Geometry Game for PDA’s

In this chapter we study an adaptive cognitive tool for teaching geometry. The study consists of two stages: First the rules of effective learning of geometry were studied. This was done by statistically analyzing user behavior in different test environments. According the analysis the adaptation rules were modeled. Secondly an Adaptive Geometry Game was implemented and its effectiveness in teaching was studied. According to the second stage test results, the Adaptive Geometry Game succeeded in improving learning significantly more than traditional non-Adaptive Geometry Games in the first stage of the study.

This study contains both of the dimensions of adaptation, defined in Chapter 3: The Adaptive Geometry Game is user behavior adaptive and platform adaptive. The main focus of this study is in the user behavior adaptive game.

The game can be played in PC and PDA environments without any differences in the user interface. The difference of the adaptation is in the rules of calculation: when the PC’s mouse is not as fast to use as the PDA’s touch screen, the time limits of user behavior must be different. In this study only the PDA version of the adaptive game was empirically tested, the limits of the PC version is estimated according to the study on preferences of PDA’s and PC’s, described in Chapter 4.

The Adaptive Geometry Game can be also adapted to other eLearning systems. There are no limits to using the Adaptive Geometry Game as a part of some pre-school mathematics learning environment. The game is developed to support one well-defined task in teaching mathematics and it only focuses on that, so it is a cognitive tool. The player can play the game without any previous knowledge of the technologies used in the game.

5.1 Learning mathematics and geometry

Mobile multimedia is the major content for handheld devices. In the context of learning or training the technology can be seen as equipment for producing and transferring human capital. In order to make more intelligent multimedia learning materials the content should be adaptive for taking care of each user’s personal skills. One of the best observers is the computer itself. By using a virtual environment as a research and observation environment the validity of research and the possibilities of transferring the results to products can both be quite good.

When approaching the concept of adaptive learning materials, we must first have conceptual models of the behavior of different learners within digital environments. The models can be given, but their implementation is not possible from a constructive point of view. Despite this, we can find some acceptable estimators for learning results which behave according to constructive rules. Mathematics software can be divided into four subgroups: 1) computational tool applications, 2) educational tools for mathematics (cognitive tools), 3) living books and 4) environments for mathematics (Multisilta 2002). In this chapter only the cognitive tool point of view is studied. The Adaptive Geometry Game is clearly an educational tool for mathematics.

5.1.1 Teaching concepts of geometry

The teaching of the mathematical concepts should be based on explanations which are studied in terms of critical thinking. This helps pupils to develop themselves as independent thinkers (Keranto 1997, 26). Relationships between basic concepts of mathematics are constructed with the interaction between a pupil and environment (Leino 1997, 42). This kind of knowledge is more powerful than knowledge which is based on remembered information (English & Halford 1995, 25-27).

A concept refers to an object, thing or event grouped together by reason of shared properties. The properties of the concept may be directly observable or internal properties which can be interpreted (the object concept), functions (the operation concept) and the relationships pertaining between them (dependence concept). The properties of a concept may be extremely complicated and they can be examined and grouped in many ways. (Klausmeier & Allen, 1978). The concept of schema is closely related to concepts and their absorption. The schema concept is used to describe the general structure relating to activity, points, situations and events. In principle even purely observational concepts are based on schemas. In this model the concepts used are built on the properties of the concepts of a certain lower level and the relations between them. In the model the concept which emerges as central are indeed complex and dependent on other concept structures. Hence they are difficult to approach.

The most known theory about learning geometry might be the van Hiele’s levels-model. This theory has been seen as a valid and useful approach for learning geometry though the levels definitions have been criticised. According to Silfverberg (1999, 26-31) van Hiele’s levels of geometrical understanding are as follows. A zero-level has been added, introduced by Clements and Battista (1992), because the zero-level is one of the expected starting levels within the sample of this study.

0) The level before geometric understanding: The pupil might have some schemas about basic concepts, but the schemas are weak and therefore the recognizing process fails often.
1) Visual recognizing –level: The basic shapes of geometry can be recognized and named. This recognizing is done according to visual shape.
2) Analysing the properties –level: The shapes are examined according to their properties, but their logical relations are not yet understood.
3) Organising the properties – level: The logical relationships between concepts can be understood and the shapes are recognized according to the conceptual definitions of the shapes.
4) Formal thinking –level: The schemas of geometry are developed so far that the pupil can construct decisions from the given definitions and rules.
5) Understanding the geometric systems –level: Different geometric systems can be understood and compared.

The pupils in the sample of this study were between levels 0 and 2 when the pre-test was done. Almost all of the students reached the first level in the post-test. Unfortunately the measuring instrument can not explain understanding after level 2.

The first known geometry learning materials for small children were the Fröbel's blocks, named after Ferdinad Fröbel. When playing with blocks the children can construct shapes from smaller shapes or divide large shapes to smaller pieces. This kind of concrete testing and developing of concepts and schemas is effective and there is no certain evidence that even the most modern digital learning materials would be better than Fröbel's blocks. Other traditional and effective geometry learning materials are Tangrams, which can be described as two dimensional Fröbel's blocks. (Riedesel & al. 1996).

A more modern geometry learning material or even learning environment is Papert's turtle geometry (Papert 1985). Turtle geometry is based on two dimensions in which the children can move with the turtle. The turtle can just be a concrete object or a shape within a computer screen. According to Papert, the computers should be used only as a cognitive tool for learning. (Turkle & Papert 1990; Papert 1999).

5.1.2 Interaction in digital learning materials

From the constructive point of view, interaction between the computer and the user is the most important issue in computer-supported learning tools. When interaction is seen as a system with inputs, given by users, and outputs, given by the computer, we can focus on the learning material by the input it requires. The dimension for this kind of thinking could be reflective vs. mentally passive input. The input should not be seen as a black and white classification, but rather as a ”gray scale” (Ketamo & al. 2000).

Passive input means a situation in which a learner can choose new input without observing and reflecting on previous output. Thus, the given input does not require previous experience or previous knowledge, and even the new media output does not require present information. The passive input is represented by WWW-documents which can be seen with the "click the mouse and see what is coming" method. Passive input can also be seen as an impulsive operation.

Reflective input reflects on a situation in which new input requires observation of the current output. Also understanding media output later requires reflection (Mezirow 1995) of previous input. Reflective input is represented by high-quality computer games and also by new learning environments, such as Lego/Logo and CSILE. Passive input learning tools can be seen as being similar to traditional printed learning materials.

The static-dynamic dimension of input is determined here as follows: If the specific input always gives the same output, then the input is static. Static inputs are so called “clicking“ links in the Internet, which always give the same asked site. Also the Internet keyword search is static, because a search engine does the same search with the same words and rules. The output could change because there could be different documents in the Internet, but the operation itself is always the same. When the output depends on several independent inputs (as time or as variable), the input is dynamic. For example, playing strategy games requires dynamic input, because playing strongly depends on tens or even hundreds of inputs and variables. In addition, learning within new learning environments requires dynamic input, because learning in these environments depends on the inputs of other learners. For learning, static input can be used for doing different logical operations, whereas dynamic input can give practice in problem solving.

When different learning resources are placed in a diagram by reflective-passive and static-dynamic dimensions, their constructive preferences can be seen more clearly (see Figure 10). The active documents placed on the top of a diagram may contain more opportunities for learning, though passive material might also be useful for a professional teacher. The static-dynamic dimension describes the way of thinking that a document requires, i.e. detailed-holistic thinking.

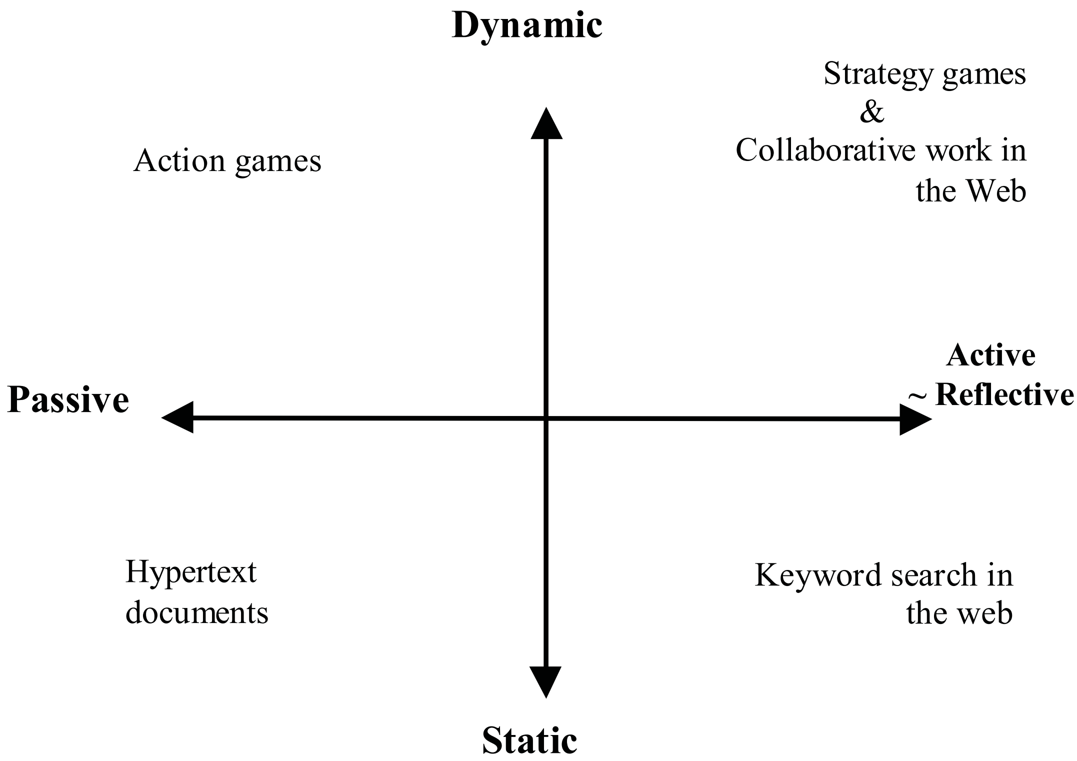


Figure 10. The dimensions of the multimedia input (Ketamo & al. 2000; Ketamo 2001a).

There are also some examples mentioned in the diagram CD-ROMs and WWW-multimedia might easily represent passive and static input. Input is passive when moving in the document structure can be done without observing the document information, and it is static when the same link or operation always gives the same result. Reflective and static input represent new media products, which can not be used without observing document information. Internet keyword searches belong to this level. Passive and dynamic input can be found from so-called action games where a player can control many inputs without any reflection. Strategy games usually require active observation and reflection, they represent reflective and dynamic input in new media. Naturally there is a whole “greyscale” for new media products and sometimes placing a product on the diagram can be difficult.

Passive learning material does not have to be less effective than learning tools that require active thinking. When learning tools require active thinking, the tool can control learning, but the same control can be done by a teacher when using passive materials. The mental activity is not the same as the activity of interaction.

Learning complex concepts or some holistic models with computers has been under research for decades (Clement 2000). Using learning materials that require reflective and dynamic interaction might provide versatile opportunities for understanding the complex world. All digital learning materials have an advantage; they motivate children more than traditional learning materials. That is a good reason to develop high quality learning products, the interaction of which is planned to correspond to the learning goals. When developing future learning materials we should be aware that a teacher's role is important among young learners: According to Sinko and Lehtinen (1998) a computer should be used to support teacher's work, not to replace a teacher.

Spatial orientation has been examined a lot in virtual environments. In 3D virtual environments the user can feel the space more personally and therefore use metaphors from the real world. Therefore 3D environments have more versatile opportunities for learning solutions than traditional 2D environments (Whitelock & al. 2000; Sanchez & al. 2000). According to Gabrielli and al. (2000) even six-year-old pupils learn spatial orientation in 3D virtual environments in an exercise on finding the way from one place to another by controlling a virtual person. In teaching geometry 3D virtual reality has been used with success (Kaufmann & al. 2000; Kameas & al. 2000). These studies were made for older students than the pupils in this study (approximately 6 years old).

5.1.3 Multimodal information processing

Multimodal information processing has been studied for a long time and from many perspectives. The Dual Coding Theory (Figure 11) is one of the most tested theories on multimodal information processing. According to the Dual Coding Theory information is processed in two channels, verbal and visual (pictorial). These channels process information in the short-term memory by combining observations of the channels. Finally the information is processed in the long-term memory.

The knowledge or conceptual structures in long-term memory are evaluated and rebuilt according to the information received and combined in different channels (Paivio 1991; Mayer & Moreno 1998; Maybury & Wahlster 1998). Bolt (1998) extends the audio-visual Dual Coding Theory with physical effects and controls by getting input from human movements and giving physical responses to user.

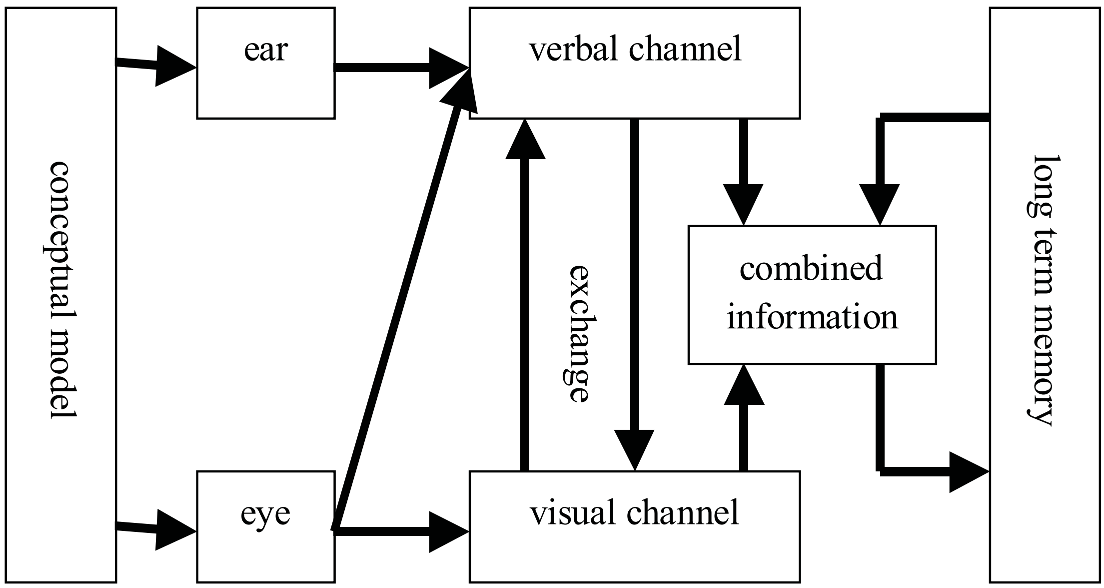


Figure 11. Dual Coding-theory according to Mayer (2000) and Maybury & Wahlster (1998).

According to the Dual Coding Theory, learning is effective when both channels are used. In general the best learning results have been achieved when combining a minimal text that is essential to the issue with explanative illustrations or animation. The amount of the text should be as small as possible (Mayer & al. 1996). When the text is replaced with speech, there is more capacity in the visual channel for illustrations and animation, and that improves the learning outcomes. (Mayer & Anderson 1991; Mayer & Moreno 1998). Speech and text utilize only the verbal channel and therefore the simultaneous use of them even reduces the learning results. (Mayer 2000). Learners find the explanative illustrations interesting and motivating in many cases. In order to achieve high learning results, the illustrations should explain the meaning of the issue, not just present a view on the issue. (Mayer 1993).

Mayer's theory of learning with multimedia is not the only approach to Dual Coding Theory. According to Hall and al. (1997) the illustrations drawn by the learners themselves led to as good learning results as the given illustrations. When using illustrations, the focus should be on the issue in the form of text, speech, or other means of information. Seductive details or entertainment takes the learners' attention away and reduces learning results. (Harp & Mayer 1998; Garner & al. 1991).

The Dual coding theory focuses only on multimedia. Thus it can not be directly applied to hypermedia, which also needs some other kind of learning theories. What is more, the Dual coding theory has been tested only with quite simple and concrete concepts, such as lightning or a pump, and therefore it does not explain anything about learning complex concepts, such as the diversity of the nature. Complex concepts must be more deeply assimilated into previous knowledge and therefore learning takes more time. For example the SimPark strategy game for children is a good attempt of bringing complex concepts into digital learning materials, even though there is no evidence that it would work better than some other methods.

In fact, there are several obstacles within all multimodal-learning approaches (de Jong & al. 1998). The learning depends on the subject, learner, instructions, tests, and time. For example Dobson (1998) presents a study on teaching logical rules to young students: The students with good mathematical skills learned the logic much better than those with no such skills, in spite of having a degree in philosophy.

5.2 Research questions and methods

The present study contains two stages (see Table 20). In the first stage the aim is to find out key factors in the user's behavior which explain learning results. In the second stage the aim is to develop an adaptive learning system. Both stages include a software development project and an empirical study.

The substudy in the first stage includes three groups of six-year-old children: test group 1 (n=21), test group 2 (n=20) and a control group (n=30). All groups were pre- and post-tested regarding their geometrical skills.

Table 20. Structure of the study.

	Group		Tests and effects	
Stage 1 2000	Test group 1	Pre-test	Learning effect Geometry game for PC – reflective input	Post-test
	Test group 2	Pre-test	Learning effect Geometry game for PC – passive and reflective input	Post-test
	Control group	Pre-test		Post-test
Stage 2 2002	Test group 3	Pre-test	Learning effect Adaptive Geometry Game for PDA	Post-test

Only the experimental groups used the learning materials on geometry, the control group did not appreciate any educational effect. The measurements were made in March 2000. In the second stage there was only one test group (n=17). That group was compared to the groups in the first stage. The measurements were made in January 2002.

Three different learning games were implemented for this study. For the first stage there were two slightly different games implemented for laptop PC's (see Figures 13 and 14). One adaptive learning game for the second stage was implemented for PDA's, namely Compaq iPaq in particular (Figure 12).

PDA's were selected because in Chapter 4 we found that PDA's were easy to use for young pupils. Especially the young users interacted fast, but impulsively with PDA's. The idea of the Adaptive Geometry Game was to change impulsive behavior to more reflective behavior, so the PDA was even a challenging platform for second stage testing.

The poor readability of PDA's (results from Chapter 4) deso not cause problems because in the Adaptive Geometry Game there is no text- based information and no need to scroll the web page. All information is presented as visual objects.

The idea of the game was the same for all the implementations. The user was asked to find and mark the required polygon. If the polygons were recognized correctly, the system allows the user to continue the game. In other cases, the system informed that there are mistakes and the user should rethink the answer.

Figure 12. The Adaptive Geometry Game on Compaq iPaq (PDA).

During these stages, one of the problems within dynamics interactions was solved. Arnes and al. (1998) presented a question about the decision-making system problematic within interactive interactions. The key points of their problematic were to 1) find rules for the machine analysis of user behavior, 2) implement these rules into the system, and 3) construct new interactive output. These problems are not solved on a general level, the result of the study provides only one solution for one case. The rules, methods and implementations can be utilized only for the purposes of this kind of learning materials.

5.3 First stage – interactive geometry game

Two different types of WWW-based learning material on geometry (polygons) were written for this study. These learning materials contain sections with reflective input as well as sections with passive input. Test group 1 got a learning effect with learning material that requires reflective input. Test group 2 got a learning effect with learning material that requires both reflective and passive input. The inputs were given only with the mouse, because all six-year-old children do not know the symbols and letters of the keyboard. The observation system in this WWW-document recorded all the mouse inputs onto a temporary log file. When a game is played, the system sends the data to a web-server, which adds a single piece of log information to the large data matrix.

The research questions of the first stage are summarized as follows:

1) What kinds of general learning results have been achieved with different learning materials?
2) In the use of different learning materials, what kinds of differences can be found between children with good geometric skills, average geometric skills and poor geometric skills?
3) Can the learning results be explained by the use of learning material?

Question 1 focuses on improvement between pre- and post tests. The improvement was viewed through different skill groups, which were defined by the quartiles of the pre-test results including the whole population (test group 1, test group 2 and the control group). The test variable, the percentage of improvement, was calculated from the primary scores by subtracting the pre-test result from the post-test result and then dividing the difference by the maximum result of the test. Thus,

$$Improvement = \frac{post\_test - pre\_test}{\max imum\_score}\ .$$

The real learning effect was also examined in this study. The real learning effect can be estimated by subtracting the learning effect of the test (control group) from the improvement percentages, separately in each skill group. Thus,

$$real\ learning\ effect = improvement - improvement_{control\ group}\ .$$

In question 2 the speeds of the interaction and the relative errors were analyzed and considered within the different skill groups. Question 3 summarizes questions 1 and 2. The explanation is examined through four variables: Real learning effect, the speed of interaction, type of interaction and relative error.

5.3.1 Learning material in the first stage

There were three types of learning material in this substudy. The differences were made by using different illustrations and different types of interaction (reflective/passive). Test group 1 used material that required reflective input interaction and illustrations that supported deductive thinking. Test group 2 used two learning materials, with illustrations that supported inductive thinking.

Passive input interaction was carried out with the help of pictures of polygons and a check-system that gave feedback only if the learner clicked at the correct type of polygon (Figure 13). The learners were asked to point out shapes at the top of the web page which are similar to shapes at the bottom of the page. When the shape is clicked, feedback is given as speech. Speech was chosen to 1) fulfill the ideas of Dual Coding Theory and 2) because written feedback is not meaningful to six-year-old pupils. When the learner thought that that a task had been played enough, the next task appeared by clicking the ready-arrow (gray arrow in the square in middle of the web page). The illustrations were below the arrow-element.

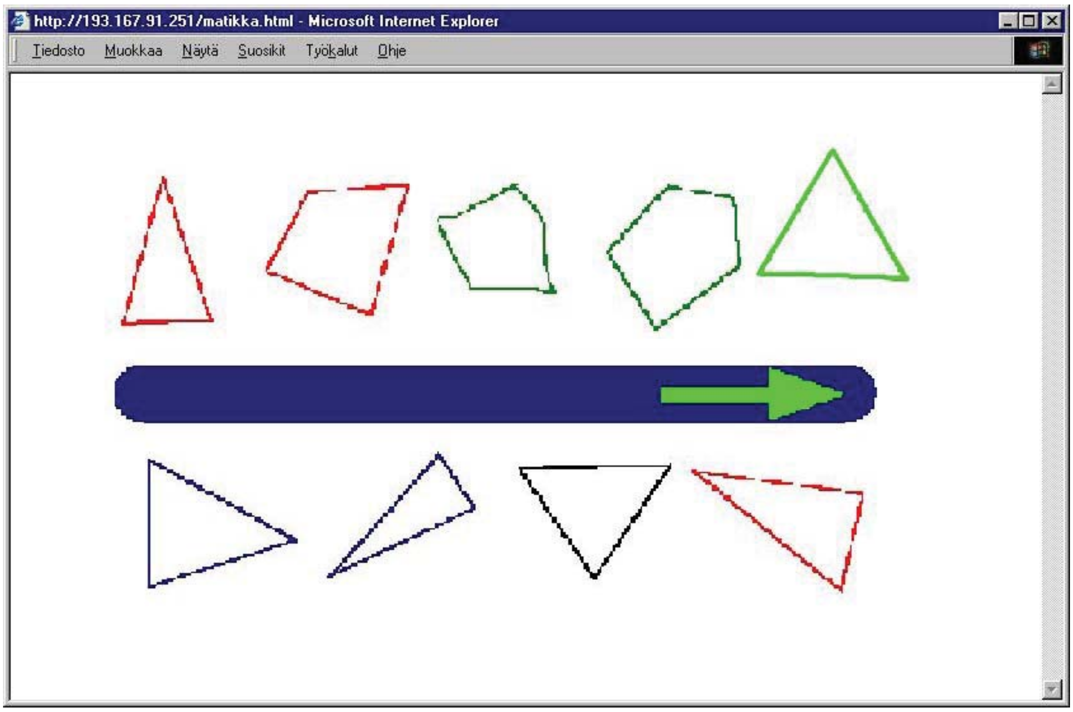


Figure 13. The general layout of the passive input tasks.

The layout of a reflective input interaction (Figure 14) looks in large part the same as the layout in passive input tasks. The major difference between passive input tasks and reflective input tasks were in the checkboxes just below the polygons. Now the learner must mark the checkboxes that represent the required polygons. When learner had decided which shapes are the requested shapes, the green arrow checks the answer. The check system does not allow any mistakes in the checkboxes when clicking the ready -arrow. Feedback in the case of an error is reported only generally, feedback was not specified to a certain element. Because there are 32 combinations from which only one could be the right answer there is not much space for guessing the answer. Also the mistake that a user had possibly made could be in any shape on the screen; the player was forced to rethink the answer. That is why this game requires more reflectivity than simple passive input tasks.

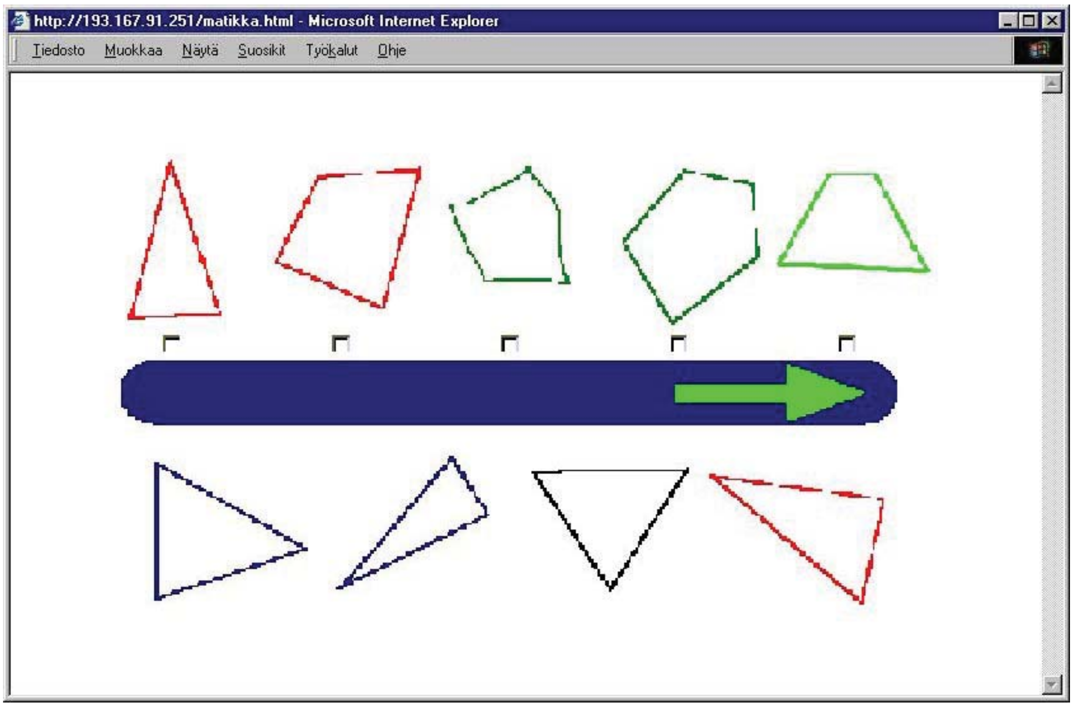


Figure 14. The general layout of the reflective input tasks.

The illustrations in the reflective input tasks were in some cases similar to the passive illustrations. In some cases, the illustration was an editable polygon, implemented in Java. The polygon could be transformed by moving the edge point with the mouse. Unfortunately only two pupils of 41 tried to use the illustrations, and it seems that the tasks and illustrations were so independent that the tasks did not require the use of the illustrations at all.

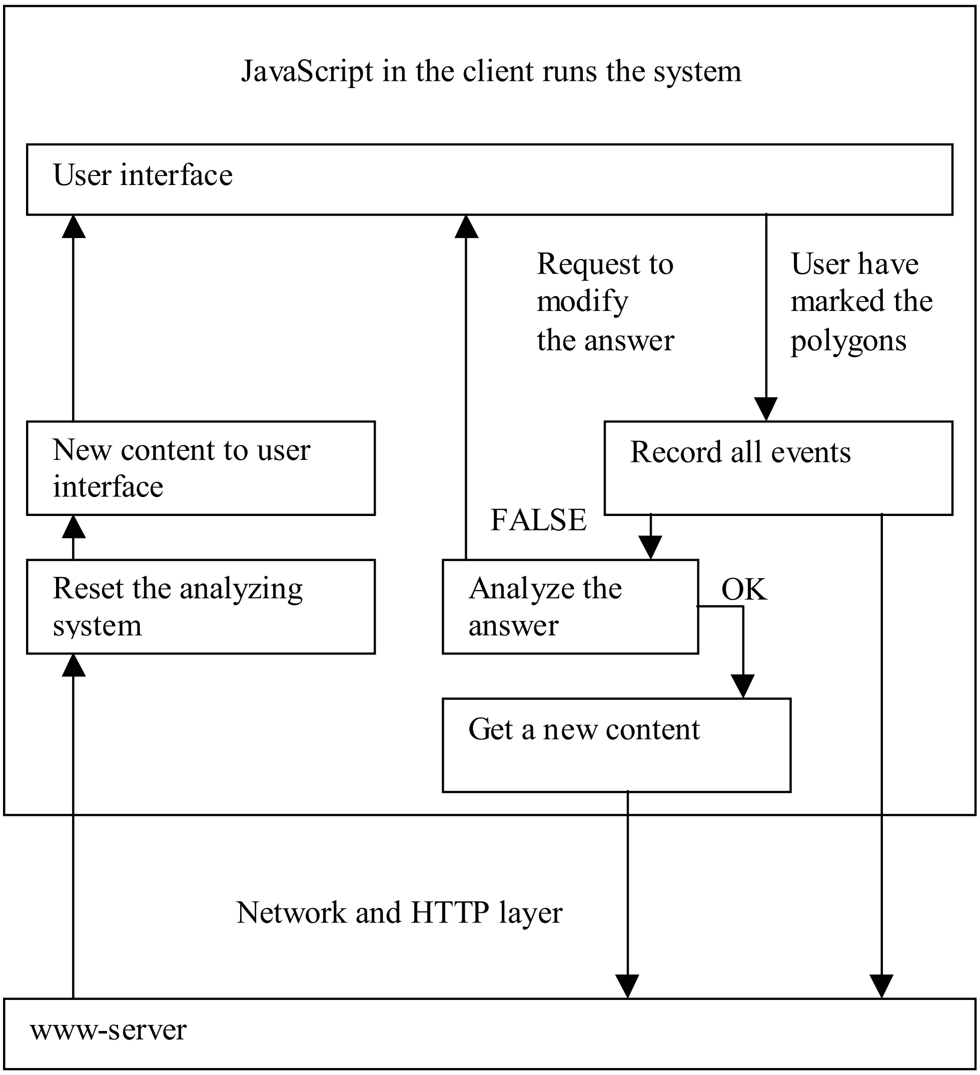


Figure 15. System interaction for the first stage game (reflective).

System interaction is described in Figure 15. A JavaScript code in the client computer runs the learning material. It records all events to a WWW-servers database and analyzes the answers. If the answers were correct, the system requests new content from WWW-server. In other cases, the system requests the player to modify the answer. The system takes care of user interface control: It decides what content is presented and how it is presented.

5.3.2 Data collection

In the study, information was gathered in two ways. 1) By a geometry test, which was a paper implemented traditional skill –test and 2) by an observation system that was embedded into the program code. The geometry test was designed to measure the geometric abilities of the pupils from three different points of view. The first point of view was recognition. The pupils were asked to distinguish the requested polygons from other polygons and shapes. The second point of view was analysis. The pupils were asked to point out a polygon, which does not fit into the concept of other polygons. The third point of view was production. The pupils were asked to draw polygons with the help of different instructions. In this study, the results of these three sections were summarized and used as a primary variable. Such a large test was implemented to improve the validity of the pre- and post testing.

The observation system, as well as the whole game, uses the HTTP- (Hyper Text Transfer Protocol) and WWW-services. First the client requests a WWW-page from the server. When an event (a mouse click, for example) is made, the WWW-browser executes the operations that are defined in the html code. The operations can be addressed to the WWW-server, but they can also be just operations inside the page. For observing the events in the page, there must be a program code which collects all the events, handles the variables and records the data. The WWW-server processes the received data using a cgi-program (a program executed in the server) implemented in PERL and sends the new source code back to the client.

In this study observation focuses only on specific elements which are the most meaningful for the evaluation of the learning material. These specific elements are pictures, checkboxes (used in exercises) and 'ready' -buttons. The checkboxes are elements that can be either marked or empty. These elements were used in the reflective input section. In this study there were only a few types of pictures: Illustrative pictures and pictures in tasks. Only events in the task pictures of the passive input sections were recorded. The ready button was recorded to find out the solving times of the sections.

The only event observed is the mouse 'click'. When clicked, each element sends three pieces of information to the data handling system: The name of the element, the clicking time and the status of the element (the status depends on the element). The name of the element is used to recognize which variables are handled by the help of information of time and status.

5.3.3 First stage results

When the two learning materials used in the first stage are examined through changes between pre- and post tests, no differences in the learning results can be found. In Table 21 the learning effects in the test groups and the control group are viewed by using a percentage of improvement. According to the percentage of improvement, both test groups improved their test results a little more than the control group, but no statistically significant differences could be found. Generally we can say that the learning effect of the test situation was bigger than the learning effect of learning materials, because according to the control group almost 8% of the improvement can be explained by the learning effect of the test.

Table 21. Percentage of improvement between pre- and post-tests (n=71).

Test group	Improvement %
Test group 1	10,8
Test group 2	10,4
control group	7,6

Different skill groups are defined by quartiles of the pre-test results including all tested populations (test group 1, test group 2 and the control group). The lowest quartile, according to test results, is represented by the low skills in the geometry -group. Two quartiles in the middle represent the average skills in the geometry –group, and the quartile that gets the best test results in the pre-test, represents the high skills in the geometry -group. The distribution of the pupils in the different skill groups seems to follow normal distribution, which means that statistical testing can be done without fittings and classifications.

Table 22. Percentage of improvement in control group (n=30).

Skill group	Improvement % =learning effect of test
low skill pupils	7,2
average skill pupils	9,7
high skill pupils	4,4

From Table 22 we can see that pupils with average skills learned most from the test. Pupils with low skills learned a little less from the testing than average-skilled pupils.

Because of the strong learning effect of the test, it is interesting to focus on the real learning effects of the first learning material. The real learning effect can be estimated by subtracting the learning effect of the test from the percentage of improvement, differently in each skill group.

From Table 23 we can see that only the pupils with low skills got real learning results from the learning material. When looking at test group 1 we can find a statistically significant difference in the real learning results between the low skill pupils and the high skill pupils (t = 2,215 p=0,044).

Table 23. Percentages of improvement and real learning effect in test groups.

Test group	Skill group	improvement %	real learning effect %
Experiment	low	18,6	11,4
group 1	average	11,8	2,1
(n=21)	high	3,1	-1,3
Experiment	low	18,7	11,5
group 2	average	10	0,3
(n=20)	high	0,5	-3,9

This result supports the findings of former studies (Sinko & Lehtinen 1999), where computer supported learning has mostly helped low skill pupils. It seems that the learning result in this study is not dependent on different types of illustrations, as supposed earlier, because the same results were achieved with both types of illustrations.

There is an interesting negative result to be seen in the real learning effect in the high skill group. The high skill test group had not learned much from the learning material, but they reached a little improvement in the post-test. For some reason the high skill control group reached more improvement in the post-test and so the negative effect is only a result of the calculation formula.

In the following examination of the results, interaction was defined to be the time between two inputs in the use of the learning material. Interaction is recorded with embedded observation which only describes the interaction between the pupil and the computer. There could be other interactions, like questions to other pupils, which are not recorded. Relative error shows the number of mistakes divided by the total number of all events. Relative error is also recorded by embedded observation.

In test group 1 (Table 24) the interaction in the low skill group was significantly slower than in the average skill (p=0,030) or high skill group (p=0,048). In test group 2, which started with learning material suitable for passive thinking, the situation is the opposite. The low skill group used slightly faster interaction when playing with the learning material than the other groups, but there were no statistically significant differences between the groups.

Table 24. Interaction (seconds in average between two clicks) in different skill groups.

	experiment group 1 (n=21)	experiment group 2 / passive (n=20)	experiment group 2 / reflective (n=20)
low skill	14,1	5,9	9,1
average skill	9,7	9,4	11,6
high skill	9,3	7,8	10,0

Table 25. Relative error (%) in different skill groups.

	experiment group 1 (n=21)	experiment group 2 / passive (n=20)	experiment group 2 / reflective (n=20)
low skill	8,7	18,1	15,4
average skill	8,9	8,4	9,4
high skill	7,6	7,7	6,3

In test group 1 (Table 25), all skill groups made approximately an equal number of mistakes. In test group 2 (first passive input - then reflective), the low skill pupils made many more mistakes than in the other groups. Although there seems to be quite a big difference, the variance in the individual cases was so big that no statistically significant difference can be found. The first stage study of this geometry game was published from several points of view in the following articles: Ketamo & Suomala (2000), Ketamo (2001a), Ketamo (2001b) and Ketamo (2002a).

5.4 Estimators for optimizing learning results

Only the low skill group achieved a real learning effect from the learning materials, which in itself is not a surprise according to former studies. The surprise is in the use of the learning materials. When low skill pupils in test group 1 had longer interactions, but made as many mistakes as others in test group 1, the low skilled pupils in test group 2 used faster interaction and made many more mistakes than other pupils in test group 2. Finally, average skill and high skill pupils did not achieve a real learning effect from the learning material, but they used the material approximately in the same way, not depending on the type of learning material in any way.

That gives us a good viewpoint of the learning effect: In test group 1, where the learning material required reflective input from the very beginning, the learners were forced to think if they did not want to make mistakes. It seems that they were thinking more than the others, because the interaction was slower, but there were no more mistakes than with other pupils. In test group 2 the learners first got used to clicking the elements during the passive input material, because the material gave feedback on a single case and the feedback system allowed mistakes. When they started using the reflective input material, which did not allow mistakes, the earlier learned way of using the material continued.

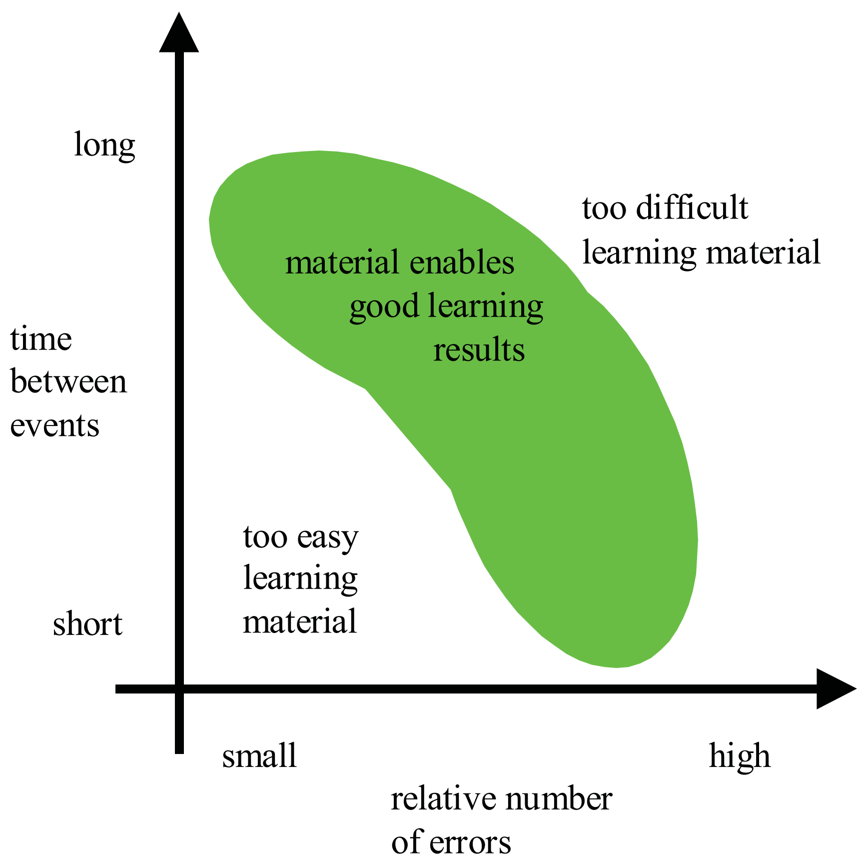


Figure 16. Estimation of the learning effect.

Reflective thinking material in test group 2 forced pupils to think like in test group 1, but they still made more mistakes, which lead to rethinking of the answer. In general it seems, that for learning to take place it is not important how the thinking effect is achieved, but the most important thing is that the material is so difficult that it requires thinking. It seems that the learning material did not offer new challenges to the average and high skill pupils and that explains part of their poor learning results.

It seems that in order to achieve a good learning effect two requirements have to be fulfilled:

1) A good control and feedback system in the learning game. This requirement can also be found from previous studies. Valcke (2002) presents that control and feedback systems in 1980-1990 were based on the cognitive load theory, but nowadays all such systems are based on user observation throughout the learning task. The observation system of the geometry game represents the newest point of view in this research area.
2) Learning tasks that require time for thinking or tasks that produce enough mistakes. The learning is information processing and real learning can not be found without reflective thinking. This requirement can also be found from other studies (Valcke 2002; Mayes & Fowler 1999).

In Figure 16 the estimated learning effect is described. Fast interaction with few mistakes has no learning effect. The most obvious reason for this might be that the learning material is too easy. On the other hand, when interaction is slow and there are lots of mistakes, the learning effect is also small. This can be explained by too difficult learning material, or by lack of motivation on the part of pupils. When the combination of interaction and mistakes are in the shaded area, there could be a good learning effect with the learning material. For example the pupil who has used a long time to find the requested polygons, but has not made mistakes, has achieved a good learning result.

5.5 Second stage – Adaptive Geometry Game

In this chapter the Adaptive Geometry Game is described. In Chapter 5.5.1 the user behavior adaptation and user interface of the game is described. Technological ideas and platform adaptation is described in Chapter 5.5.2.

5.5.1 Behavior adaptation and user interface of the game

The Adaptive Geometry Game inherits the best parts of previous reflective input interfaces (Figure 17). The game layout is built in quite a minimalist manner as the general usability heuristics suggests (Fleming 1998). There was no confusing entertaining content (Harp & Mayer 1998; Garner & al. 1991). Only one stabile illustration was used, though pupils did not use illustrations at all in the first study. The illustration was also meant to show the requested shape. The polygons to be recognized were below the illustration and the ‘check’-button.

The educational ideology of the game is to provide an environment for conceptual recognition (Penner 2001). The interface was designed to fulfill the requirements of an economy of action and time (Fleming 1998, 14; Maes 1998; Raskin 2000, 2) and it proved to be simple and easy to use in the pre-test of the game.

When discussing the Adaptive Geometry Game in the terms of the usability study in Chapter 4 we can find several useful models from the empirical results of the study. 1) The whole PDA screen was fast to use as an input device and there were no reasons to limit the interaction buttons into some part of the screen. 2) Because in the game there is no scrolling system the interaction could be as fast as interaction in the pointing test. Naturally there is also time for recognizing shapes, but the interaction itself can be expected to be fast in the PDA environment.

The recognition speed is a critical factor of the adaptation system and the influence of pointing speed naturally affects the observed recognition speed. The observed recognition speed includes pointing speed and real recognition speed. In this context fast pointing, supported by PDA’s, improves the adaptive systems’ reliability because the amount of real recognition speed increases within the observed recognition speed. In general, according to results from Chapter 4, we can assume that PDA’s are theoretically more reliable platforms for this game than PC’s.

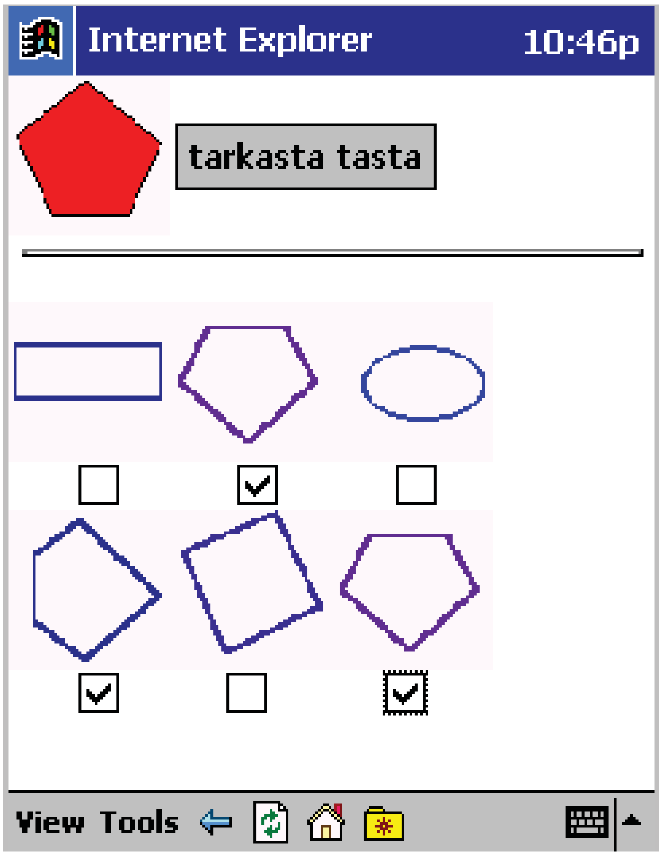


Figure 17. PDA user interface for geometry game.

Mayes and Fowler (1999) suggest that there are enormous risks of spoiling the learning material with the wrong kind of user interface. When usability is high, the risk of spoiling reflective thinking activities is enormous. The testing system implemented should be easy to use, but there should be no risk of passing the test without real knowledge. The simplified conceptualization process according to Mayes and Fowler is presented in Figure 18.

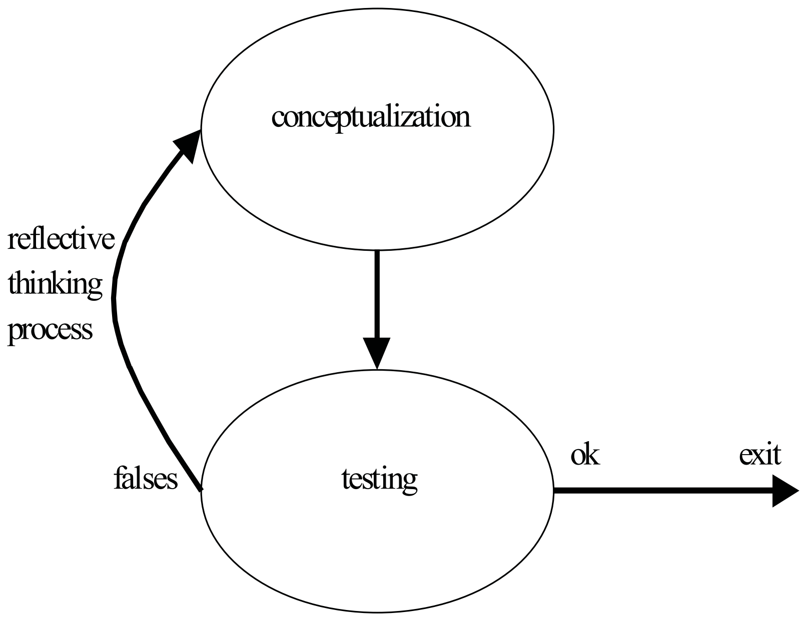


Figure 18. The conceptualization process according to Mayes and Fowler.

In the geometry game a good conceptualization process is ensured with 'multiple right answer' tasks. There are 64 combinations of answers, so the risk of getting the right answer by guessing is less than 2% and the risk for getting two right guesses is almost zero. The requirement for a user-friendly interface was ensured in the pre-test of the game.

The adaptive learning game naturally requires more than scalability to different platforms. The calculation rules (Figure 19) for learning result optimization were developed according to the results of the first sub-study. The rules represent a non-linear system where previous and new interaction is recorded and the learning result (the state of the conceptualization process) was estimated according to these data. A more sophisticated version should use neural networks, but the observed rules can be modeled with this kind of simpler system. To make the web server workload smaller, this simple set of rules was selected.

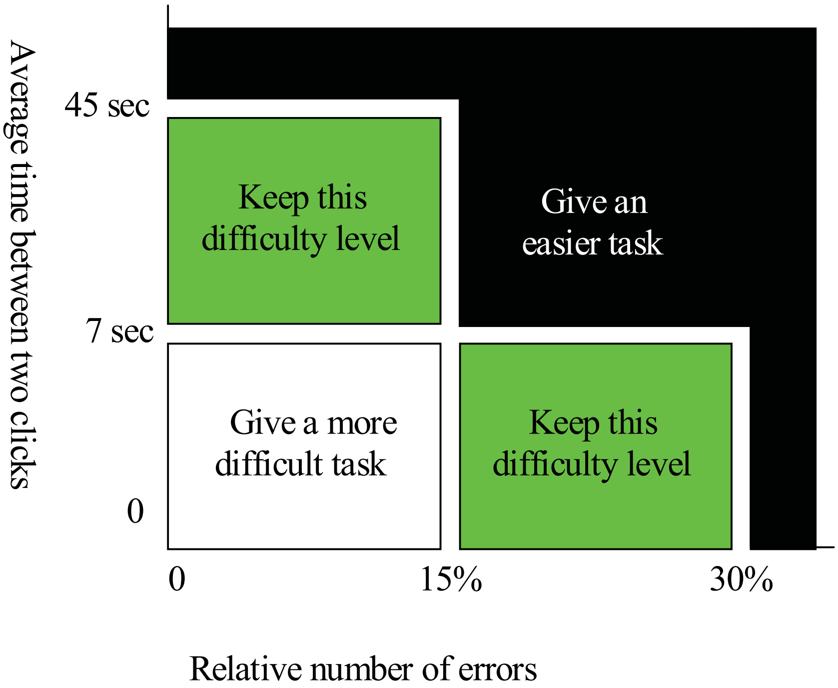


Figure 19. Calculation rules for optimizing learning results.

The calculation rules were executed on a WWW-server and according to the rules, the following display was constructed. The system constructs the new interface partly by randomizing the presented shapes according to calculation rules. With this solution it is almost impossible that the same interface appears twice to one player, no matter how long the game takes.

5.5.2 Platform adaptation and technological description of the game

The second stage the geometry game was implemented for a handheld computer. Handheld computers provide new opportunities for teaching and they seem to be suitable for this kind of a solution. In fact, handheld computers with a touch screen are likely to be faster to use than PC's with a mouse. The second version of the geometry game was implemented for both PC's and PDA's (Compaq iPaq).

When the PDA version of the game was tested, the assumption about easily utilized hardware proved to be true. The pupils immediately learned to use the touch screen and the use of the handheld computers was easy for them. This could be expected according to results from Chapter 4, where PDA's were found to be easy to use among pupils.

The platform adaptation of the Adaptive Geometry Game (Figure 20) is simple: There is a base HTML document which includes XML definitions for two system elements. The base document for PC's and PDA's user interface differs only slightly by page layout, but there is no need for that – the interfaces could be completely different if needed. The XML defined system elements were the JavaScript and the shapes to be displayed in the game.

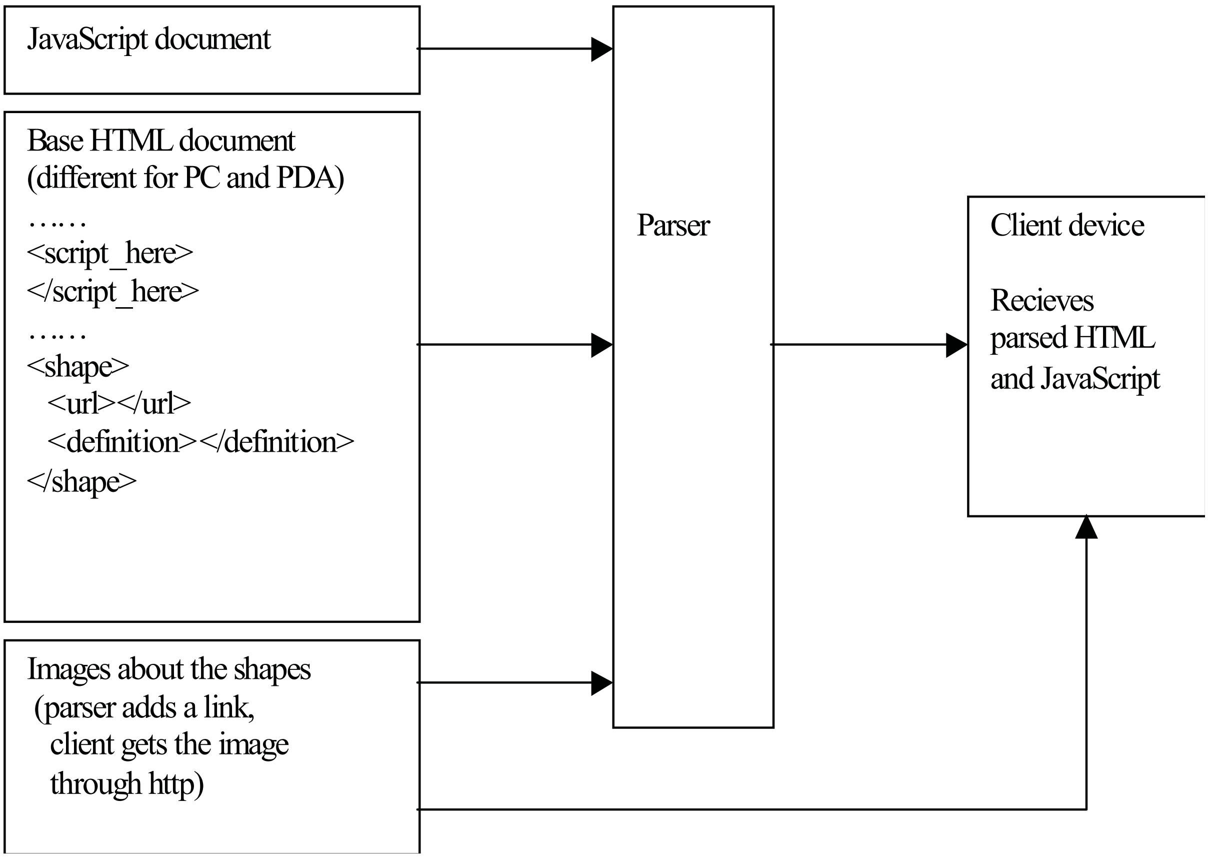


Figure 20. The description about platform adaptation of the game.

The user interface design for PC environment would be challenging: According to results received in pointing test (Chapter 4), the mouse device is slower to use than touch screen. The Adaptive Geometry Game is more reliable when the pointing times are minimal. This means that whole PC's screen can not be used for the game. That is why the page layout between PC's and PDA's are quite similar in this thesis.

JavaScript code was simplified according to the limitations of PDA's scripting and therefore only one JavaScript was used. The script is stored also in a separate document and it is parsed into the base HTML document in server. JavaScript was excluded from the base HTML document because in this solution we can modify the user interface easily without a risk that modifications would harm the functionality.

The same idea is applied to the shapes. The images about shapes are stored in a server and they are dynamically linked into the game. Links as well as the definition of the shape are parsed into the base HTML document in the server. Definition includes information about whether the shape is requested or not. There are differences in parsing links and definitions: Definitions are parsed to JavaScript but links are parsed to HTML. Finally the parsed HTML document is sent to the client device.

The system level operations of the Adaptive Geometry Game are described in Figure 21. The parser (left, bottom) described above is only one small part of the whole solution. In testing the PDA's were connected to a server with a wireless network, which is the most powerful way to utilize these terminals. The wireless network behaves as if it were wired and the network is invisible for http-services in that way.

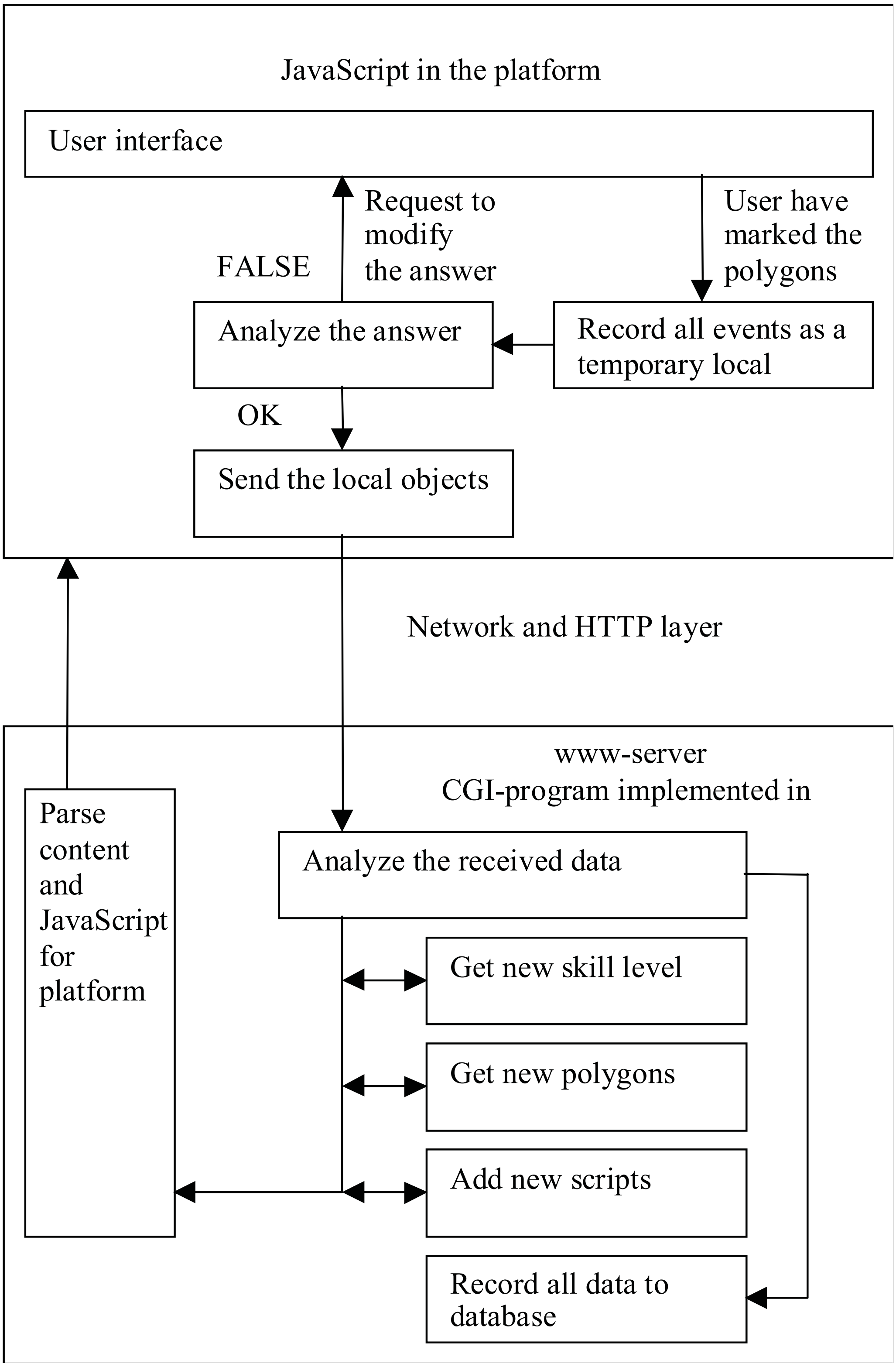


Figure 21. Interaction in the second stage game.

The client operations are the following: 1) To observe user behavior, 2) Pre-analyze the recorded data in order to lower the use of the network and 3) when the task is done, send the pre-analyzed information to the server.

The server operations are the following: 1) Calculate the new skill level according to behavior adaptation rules, 2) according to skill level, modify the new task (including scripts & links) and 3) parse new task for client.

As we can see from Figure 21, most of the functions are executed in the server. The behavior adaptation process is done in the server according to data received and limits set beforehand. All data is collected to a database for further studies. Every time a new learning task is requested, the server sends an individual learning task to the client with new directions for actions and a new user interface.

5.6 Results of the second stage

From the very beginning, it seemed that the PDA version of the game is better than any of the old versions of the geometry game. Pupils were interested in and motivated when playing the game. Even those low skill pupils, who hardly got any points from the pre-test, played the game without complaining. The motivational issues might be one of the explanations for the good results, though the learning results optimizing rules seemed to play the major role.

On the average the pupils played the PDA version of the geometry game for 25 minutes, which is a little less than the playing time for the PC version of the game. The shortest playing times were under five minutes and the longest playing times were more than 40 minutes. The generally shortened playing times were partly achieved with faster pointing system of PDA's (result from Chapter 4).

The playing time or tasks played do not explain the learning results, which is a good fact. The system was designed to optimize learning results according to the behavior of players. It seems that the rules worked from this point of view: In the first stage the observed behavior explained learning results. For the second stage rules were formed to optimize some behavior when the same effects could not be found from the second game.

In this test group there were no high skilled pupils. It seems that the low skilled group benefits again more from the learning game than the average skilled group (Table 26). There is a statistically significant learning effect reached in the whole test population between the pre-test and the post test (t=-2,961 P=0,004) compared to first game learning effect. When comparing the learning effect of the PDA version of the game to the control group, we can see an even more significant difference in learning (t=-3,947 p=0,000).

Table 26. Improvement and the real learning effect.

	Improvement %	Real learning effect %
Low skill group	32,0	24,4
Average skill group	17,4	9,8

Table 27. The number of pupils in different skill groups.

	Pre-test	Post-test
Low skill group	6	-
Average skill group	11	12
High skill group	-	5

When comparing these results to the results of the first stage, we can see that the PDA version of the game achieves a double learning effect in the low skill group. In the average skilled group the PDA version of the game has almost the same effect as the first version on low skilled pupils.

The most important result was that all the low skilled pupils reached the group represented by the average skilled pupils (Table 27). This is important in order to give all pupils the same possibilities in the future.

The results from the second stage, including technological implementation and empirical results, has also been reported on Ketamo (2002b) and Ketamo (2002c).

5.7 Evaluation of the geometry game

The aim of this study was to develop a system that adapts to the behaviors of users. Despite the fact that the adaptive system in this study was very limited and the observed behavior was defined as being very simple, the PDA version of the software worked well.

The most important result was that all low skilled pupils reached the level of the group represented by average skilled pupils. This is important in order to give all pupils the same possibilities in the future. The tested population in the second stage was quite small. The population was small because the technology used is new and all the systems must be installed in the schools for testing. There were only limited resources for use in testing. The small population naturally lowers the significance of the second stage results.

On the other hand, the results achieved were quite clear and the results were not meant to be general properties of learning materials. The results were only meant to fulfill the needs of this study. When transferring these ideas to other learning games, the factors and the limits for the adaptation system should be examined from the departure point of the learning material.

Though the PDA version of the geometry game worked well, some development has to be made: When the player gets tired, which is quite usual with six-year-old children, the player's behavior changes a lot. The system should be taught to understand when unexpected behavior is about lack of skills and when it is due to tiredness. The second issue that needs improvement is the user interface. Though the children used the touch screen well, they still made some mistakes by accident. User interface development is technologically easy, because the user interface is its own component for the system. From a methodological point of view development could be difficult, because usability and learning outcomes of the software should be remain.

This study shows that we can easily help low-skilled pupils with certain technologies, so technology is definitely worth developing. The learning effect was promising with this kind of a simple adaptation system and we can only imagine what kinds of effects we can achieve with more complex systems.

The geometry game can be developed in two ways: The adaptation rules can be sharpened even more. Now there is an assumption that the good skilled pupils do not benefit from the game. There is still a question if the good skilled pupils can be taught by computer environment: When the conceptual structures are well developed and there are no misunderstood relations, the conceptual change requires either totally new information or some kind of confusion. In case of creating an unnecessary cognitive conflict we can even harm the natural development of the pupil by mixing his or her conceptual structures. The geometry game can also be extended to cover more shapes when the target population is wider. In the case of the extension the adaptation rules must be redefined.

6 xTask – platform adaptive groupwork environment

In this Chapter xTask is presented as a platform adaptive web-based learning environment but it is evaluated also in terms of user behavior adaptation. The user behavior approach, based on empirical study, was done in order to find out and explain some possibilities for user behavior adaptation within xTask. Some results of the usability study, described in Chapter 4, were applied in xTask's development. On the other hand, the empirical study of xTask shows that some results of the usability study can be found also in larger contexts.

xTask is a server-based application operating on a WWW browser. All communication between a client and a server is carried out using the HTTP protocol. The xTask environment is built over an Apache web server, Perl API, and MySql database. These were selected for the platform because of their computational speed and functional reliability.

The descriptions of older versions of xTask were published in ED-Media 2001 (Ketamo & al. 2001b) and in WCCE 2001 (Ketamo & al. 2002a). The studies described in this chapter were published in shortened and especially thematically targeted form according to requirements of following conferences: ITK'02 (Ketamo & al. 2002b), WMTE2002 (Ketamo 2002d) and IRIS'25 (Ketamo & Suominen 2002). The published studies focus on xTask from several points of view: the ITK'02 presentation focuses on studying with mobile technologies, the WMTE2002 paper focuses on mobile platform and the IRIS'25 paper focuses on group work.

6.1 Requirements and research questions

The need for a simple to use, modular and platform independent web-based learning environment is obvious. Most web-based learning environments of today do not support mobile platform connections (such as PDA) in order to fulfill the needs for place independent distance work.

The aim of this study was develop a platform adaptive group work environment for university courses and enterprise training. The main parts of the implemented environment is described, especially the two tools which were used in the empirical study are described in more detailed than those tools that were not use in the empirical study. The requirements for the platform adaptive group work environment (described in Chapter 6.2) were following:

1. The system should be adaptive to different devices (in this case Compaq iPaq, Nokia Communicator and a PC).
2. The system should be easy to use in order to support real work in the environment, not just learning to use the environment.
3. The system should be as minimal as possible but still support a maximized set of learning and working tools including the following: 1) personalized content and interfaces, 2) communication, 3) a library area for learning materials, 4) document and idea processing areas (described in more detail in Chapter 6.2).

The research questions (answered in Chapter 6.3) of this study can be divided into two groups: empirical analysis on xTask use (questions 1 and 2) and future developmental ideas of xTask (question 3).

1. How much and in what context did the students use mobile devices in studying?
2. How using mobile devices affects the quality and quantity of work?
3. According to work processes, can ideas for user behavior adaptive extensions for xTask be found?

6.2 Implementation of xTask

Implementation of xTask is described in three Chapters. Chapter 6.2.1 describes the xTask's shell, which is the backbone of the whole system. Shell connects the individual modules to a system. One of the main ideas of xTask was modularity: the possibility of bringing new modules into the system easily. Therefore the shell was built as an independent module.

The platform adaptation system, described in Chapter 6.2.2, is a subroutine in xTask's shell. Because the implementation of adaptation system is an important feature of xTask it is described in its own chapter.

XTask's tools are described in Chapter 6.2.3 – 6.2.5. The tools were compared to tools in the WebCT environment. WebCT was selected because it is one of the most widely used network based learning environments. Only the two tools that are used as main group work areas for the empirical study and which are evaluated in the empirical study are described in more detailed.

6.2.1 xTask's Shell

In a traditional definition, a transaction shell contains both authoring and delivery systems. The authoring system is built for a teacher, and the delivery system is built for students. The delivery system is controlled by instructional interactions, defined in the authoring system. These interactions, as well as pieces of content, learning objects, are stored in a database. (Li & Merrill 1990; Merrill & al. 1991). As transaction shell ideology has influenced XML ideology, it provides a concrete model to separate content, structure, and interactions. Nowadays we can implement all this with the XML technology family. XML technologies are not the only starting point for the management shell. The database systems and other server software can be made faster and more reliable with the combination of XML technologies and "older" technologies, such as relation databases.

An ideological background for xTask's shell can be found from MPEG-4 and Dexter Hypertext Reference Model. MPEG-4 can include many different media types in one scene: HTML-pages, video and audio clips, graphics and application windows (Koenen 1999). An older, but more useful approach is the Dexter Hypertext Reference Model, which was described in 1988. (Halasz & Schwartz 1994). The Dexter Hypertext Reference Model describes the system in three layers: the runtime layer, the storage layer, and the within-component layer.

In xTask content, structures, operations, and interface are separated from one another. In Figure 22 general communication between terminal, xTask shell, modules, and databases are illustrated. The xTask shell is a transaction shell-type case (Li & Merrill 1990).

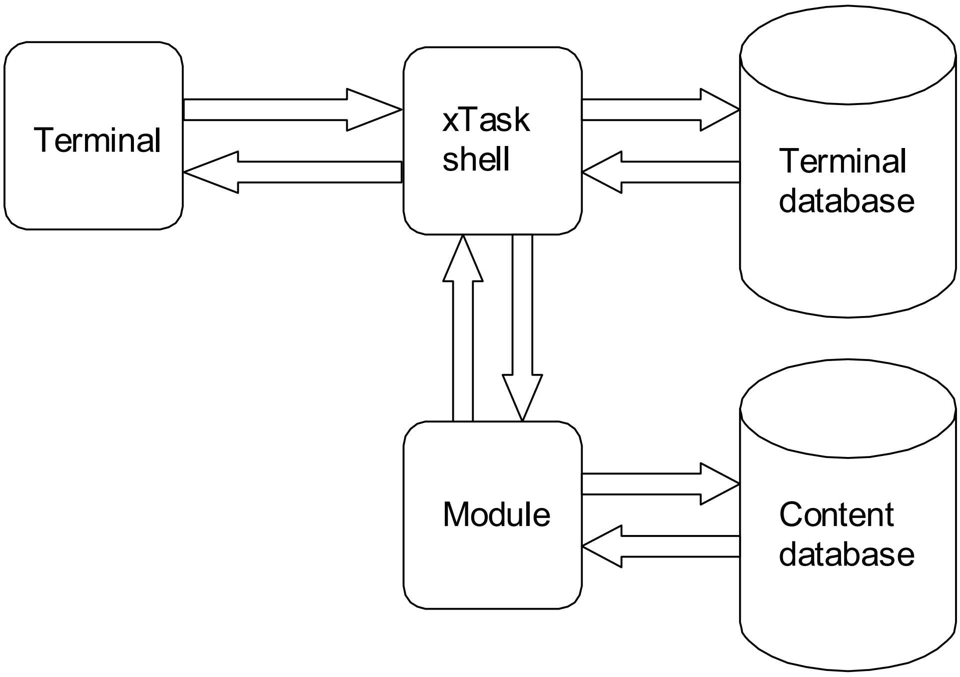


Figure 22. Overview of xTask module and database structure.

When connected, the xTask shell identifies the terminal and loads the login-module with a terminal compliant interface. The login module is one of the xTask's built-in modules.

Through the xTask shell, most of the CGI programs can be embedded into xTask. The login module has another special feature. It uses a Recourse Description Framework (RDF) influenced (W3C 1999) user database, which contains user interfaces, tools, and resources (Figure 23). Each user profile can be built individually without any restrictive structural limitations. Though the database utilizes RDF methods, it is built on a traditional relation database and the program code is written with graph -based methods rather than RDF based ones. The influence of RDF in the login structure is noticeable, therefore RDF is mentioned.

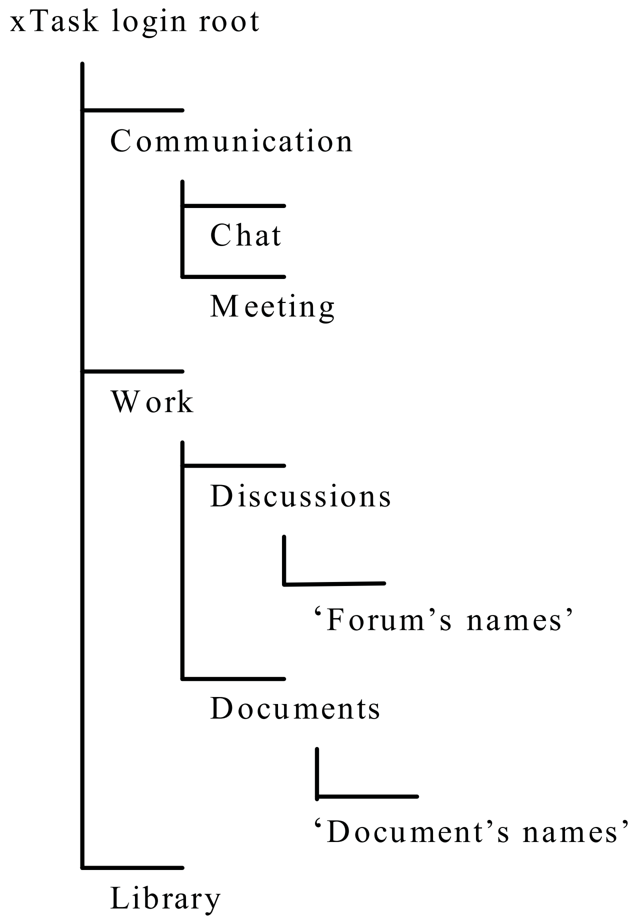


Figure 23. Example: Hierarchy-structure to build xTask user interface.

The user's view is constructed in the shell from a combination of all information in such a way that the terminal requires. The user interface structure described in Figures 23 and 24 refers to the default 'guest'-user in xTask. In the database structure each object belongs to one IsPartOf-group. The IsPartOf-group tells to which sub-menu the object belongs. IsBasedOn – class describes the URL of the module that handles the object. If module is 'login', the object is a part of the menu-structure and it is acting only as a parent-object to make the interface easier to use. In the example there are no objects used outside the server.

Object	IsBasedOn	IsPartOf
communication	login	xtask
work	login	xtask
library	library.cgi	xtask
Chat	chat.cgi	communication
Meeting	meeting.cgi	communication
Discussions	login	work
Documents	login	work
‘forum name’	discussion.cgi	discussions
‘document name’	document.cgi	documents

Figure 24. Example: database structure to build the xTask user interface.

Because of the RDF type login module the content and the content handler do not need to know each other and that helps to import new modules and features to xTask. All xTask’s built-in modules behave like the login-module. All built-in modules also use databases modeled especially for their needs. The xTask inner content and structure presentation have had a lot of influences from XML although the presentation is not fully XML compliant in the meaning of W3C recommendations (W3C 2000).

When dividing the xTask’s shell operations into main groups, we can find two major operations: terminal device recognition and user recognition (Figure 25). The terminal is recognized according to HTTP layer background variables, which can be used easily within Perl or Java environments (The adaptation system is described in more detailed in Chapter 6.2.2).

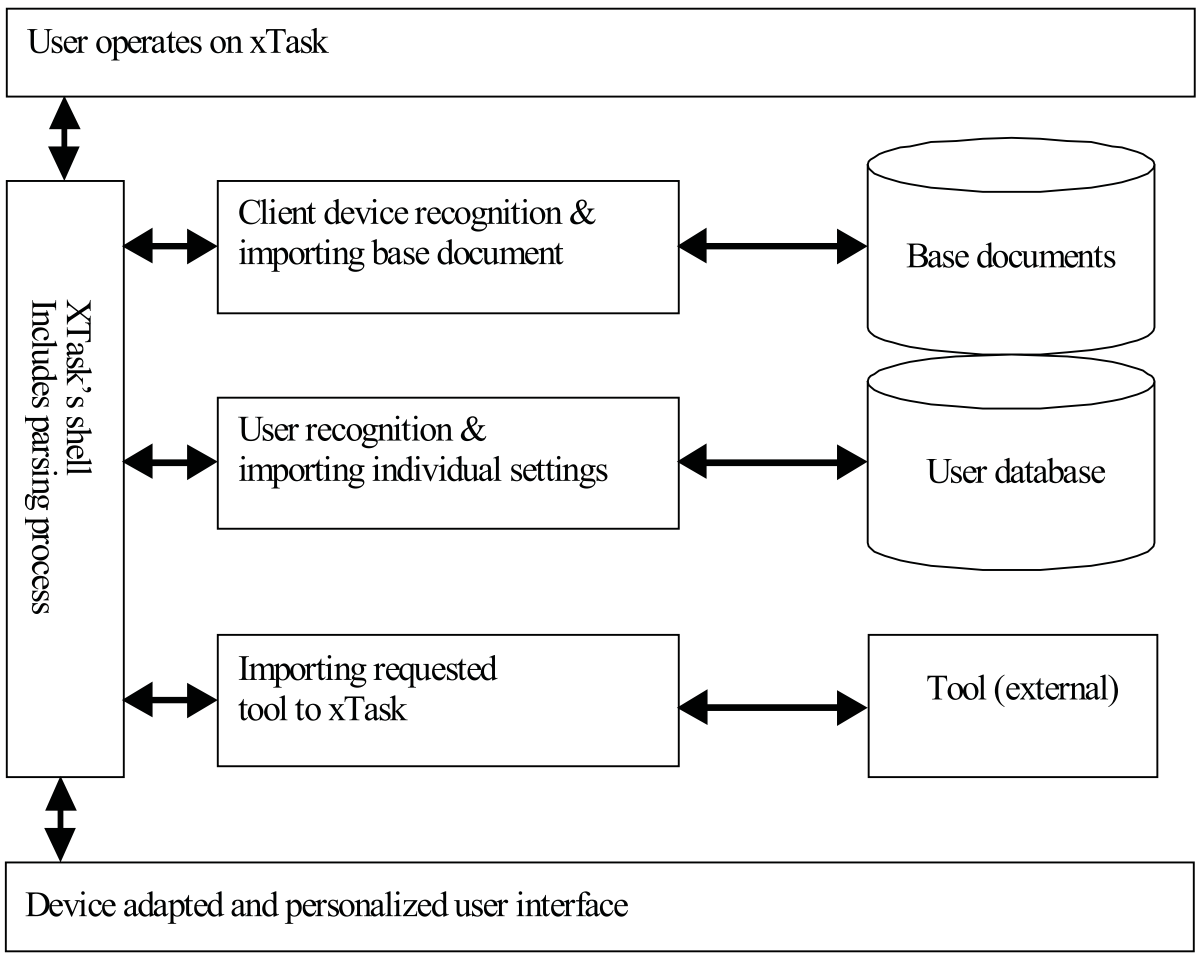


Figure 25. The xTask system description.

User recognition is done according to username and password. If the username is not given or the username does not exist, the default interface is given for testing the xTask. The external modules are imported into xTask through the shell. External in this case means all modules that are external to xTask's shell. xTask does not differentiate between its own tool modules and other external cgi-based tools. The shell makes HTTP-queries and receives text-based information from the tool (text based information can be HTML or XML). All this information is parsed into the XHTML document.

Having personalized users is a fairly obvious starting point for all web-based learning environments. It is only natural that different users have different rights within the system, in which case users must be personalized in order to identify these rights. With regard to data protection this is also an essential feature in the software: 1) External users can not access the personalized system, while workers can access the system from more than one "pipe", 2) It is possible to monitor activities in the system, and workers' ideas and thoughts remain personalized. When a user only gets to see the tasks and tools, which are assigned to him, it becomes much easier for him to navigate in the system, thus the user can direct his energy to the work itself.

6.2.2 Platform adaptation in xTask

Platform adaptation in xTask was implemented with quite similar methods to platform adaptation in the Adaptive Geometry Game. In xTask there was much more complex XML structure in the base document.

Base documents are the background that includes all platform specific scripts and layout structures (Figure 26). Information from other modules is parsed into XML-defined places in the base document. XML information from other modules is included in the base document to describe containers for the navigation bar, menu structures, menu items and the work area. xTask places information received from external tools or modules in the work area.

xTask's shell fetches all information that is needed in the parsing operations. The information that is used depends on the base document. For example in iPaq's and Communicator's base documents there were simpler navigation structures than in a PC's base document. Also page layout differs a lot between platforms: When in iPaq the whole 240x320 was usable as a touch screen. Building navigation for it was easier than for Communicator's 640x200 screen. As explained in Chapter 4, the touch screen was fast to use. The same does not apply to Communicator's navigating elements. Communicator's screen was not a touch screen and building navigation for it was difficult. In the end it was more confusing than iPaq's navigation structures.

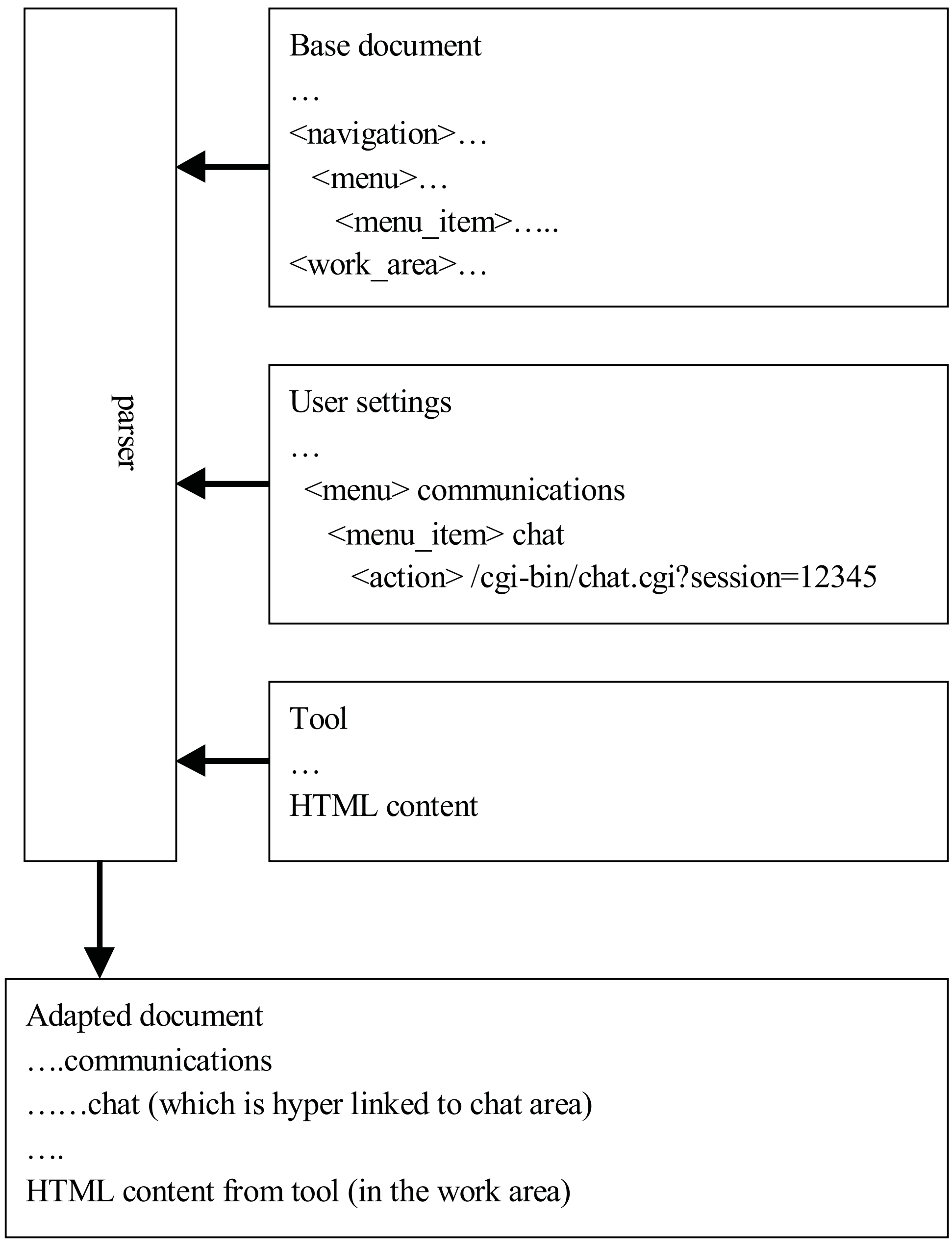


Figure 26. The idea of xTask's platform adaptation.

When embedding tools from other web-based systems this kind of parsing works well in most cases. In some cases the layout of the page is not possible to convert to PDA's, the fitting operations in xTask are quite limited. The biggest problem when trying to work with tools from other web-based system with PDA's is scripting. For xTask's tools there are a limited set of base scripts which can be used in different platforms, but xTask can not afterwards modify scripts adaptive for PDA's. Because of that, most systems that are using scripting (BSCW for example) can not be used with PDA's through xTask.

6.2.3 xTask's tools

In this Chapter the tools of the xTask are described. The tools are the library, idea development areas, document development area, chat and video conferencing. The tools are described briefly in this chapter. From an adaptation point of view the tools are not meaningful because they were implemented to use XHTML Basic for all interfaces. This was done in order to simplify the parser system in xTask's shell. XHTML Basic is a simplified set of XHTML elements designed PDA's and especially hand-held computers. The XHTML Basic works naturally in PC browsers as well, so it was an easy choice for tool description.

The tools that are utilized in the empirical study are described in more detailed. The empirical analysis focuses on platform adaptation in terms of platforms and tools. The tools in the empirical study are the idea development area and the document development area.

The special features of xTask may be considered not only as being non-platform dependent but also user friendly. The user interface of the environment is described on a general level. The user's view is divided into two parts: the navigation panel and work area. The navigation panel includes all the core functions for the use of the application. The navigation panel is designed so that there are minimized distances between operations in order to minimize the time used for navigation (see Chapter 4). This makes it possible to use large touch screens with acceptable speed use.

All interfaces use quite similar navigation panels (Figure 27). The PC navigation panel gives more detailed navigation support than a PDA's navigational panel. This is done to improve the PC navigation speed – according to studies in Chapter 4 the PDA navigation speed was better than a PC's, so there was no need for extra support. On the other hand, if similar navigation support had been built into PDA's, scrolling systems should also be used in the navigation panel. In Chapter 4 we found out that when scrolling was used with PDA's, the reading speed was lower than without scrolling. This indicates that scrolling should not be used in the PDA's navigation panel.

When comparing xTask's navigation panel (Figure 27) to WebCT's navigation (Figure 28) we can see that xTask's navigation is simple and centered in a small area. In general, the navigation in xTask was evaluated as being clearer and easier to learn than navigation in WebCT (Kiili 2002).

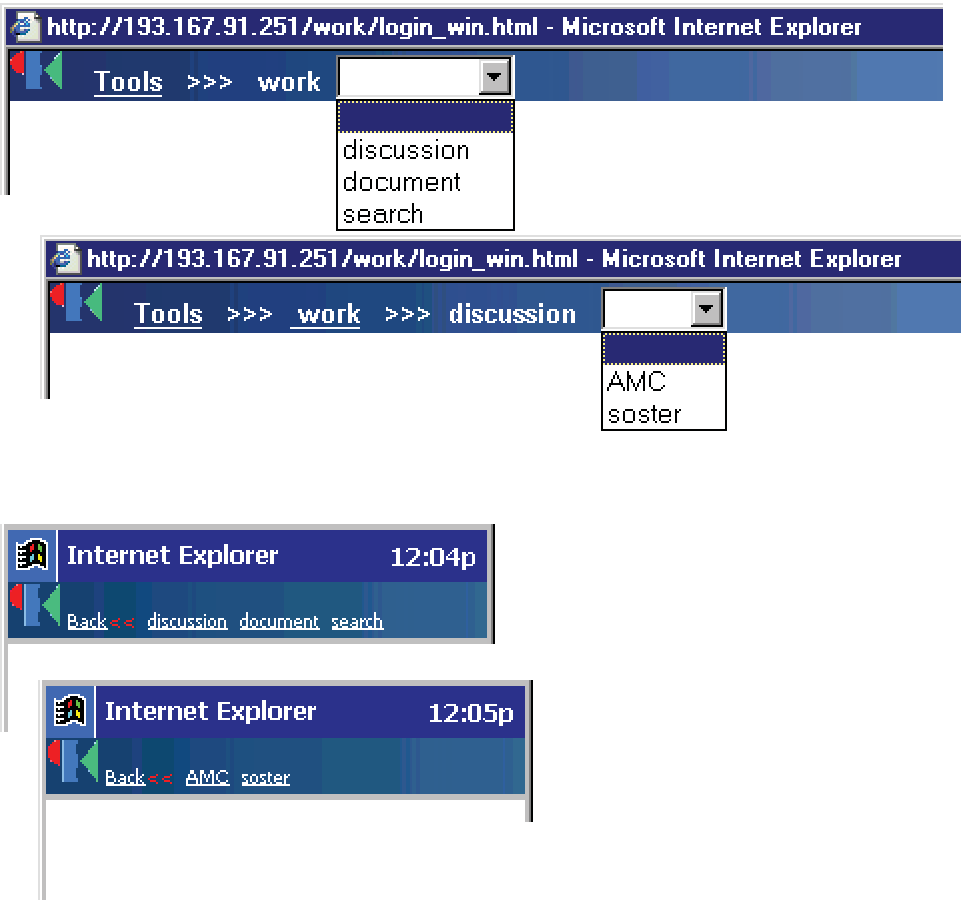


Figure 27. xTask's navigation panel (top PC's navigation, bottom PDA's navigation).

The navigation in xTask was designed so that the usability remains also in touch screens. This feature has not been taken into account in most of the web-based learning environments. For example, in WebCT the most of the navigation is in the top of the screen but some navigation features are in the left side of the screen (Figure 28). In some cases this may cause long eye and mouse movements that could slow down the navigation process (Chapter 4).

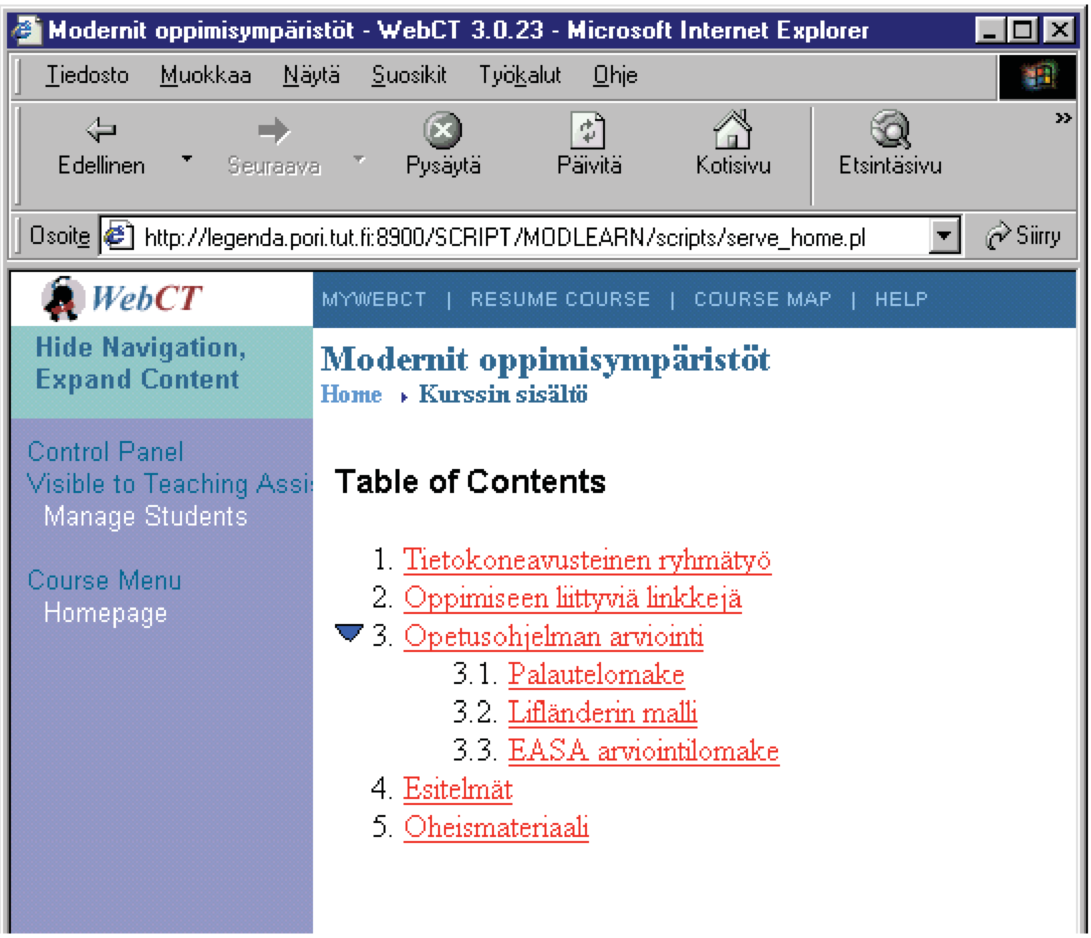


Figure 28. WebCT's navigation areas.

All the students participating in the study felt that xTask was easy to use. The following two comments summarize students' opinions about navigating. The comments were originally given in Finnish and translated later.

> *"xTask's user interface is good. It is very simplified and it is easy to learn and remember."*

> *"The navigation system is simple and systematic. The navigation panel fulfils Nielsen's ideas about good navigation: A user recognizes a) where to go and b) where s/he has been."*

Though the navigation was felt to be good several suggestions about other functions were offered. Those suggestions are presented when the specific tool is described.

The library is a CGI-module that lists materials and documents available to users. If needed, the materials and documents within the library can be loaded into other software on the device. For example video clips or eBooks can be downloaded into programs that are defined in the client device for the given MIME-type.

The library can also be seen as being an extension for the navigation panel's menu structure. Those tools that are not used often can be linked as library items in order to save space in the navigation panel. Also, tools that are often used in the library area can be added to the navigation panel's menu structure.

Communications features are the basic tools of group work, regardless of the system used for the work is. The text-based modes of communication can be roughly divided into three main types: electronic mail, chat and discussion areas. Chat and discussion areas are many-to-many systems, although they can be made to transmit one-to-one discussions as well.

The main difference between chat and discussion concerns the time concept: While chat communication is based on brief here-and-now comments, discussion areas generally, in contrast to chats, can also be read and commented on later. Audio and videoconferencing constitute a group of their own, facilitating simultaneous communication in work groups and naturally are more appropriate tools for on-line negotiations than text-based chat.

In the present application chat is the only communication tool to be implemented in all the platforms. The chat in xTask is a simple text-based linear discussion area that only shows the ten newest messages. Chat is meant only for short, time-dependent messages. All meaningful information for working or learning should be said in the idea development area or in the document development area.

Videoconferencing was not actually taken as a communication tool nor was it implemented in PDA since poor network capacity within GSM data would not support the use of videoconferencing. Another problem is the PDA itself: a stable videoconferencing module for iPaq can not be found. Videoconferencing in a PC environment is based on Microsoft Netmeeting components transferred to the WWW environment. There is one benefit using Netmeeting as a tool for xTask: xTask records client IP's when connecting. By utilizing this client IP recognizing system the user can directly call another xTask user, who is online.

Library, chat and videoconferencing are tools that do not provide much new. Library and chat are included almost every web-based learning environment and adaptation in these tools is done by XHTML Basic. The IP recognizing system does not exists in WebCT, but it has been used in several web-based learning environments: For example R5 Vision's Generator –environment and TietoEnator's atLearn –environment has similar features.

6.2.4 Idea development area

The use of discussion areas has been seen to be a good method in the development of expertise and argumentation (Marttunen 1997; Hakkarainen & al. 1999). This, however, presupposes that the tasks assigned are both challenging and open but at the same time include precise definitions of the goals and rules of play. Such tasks are indeed difficult to invent and a poorly conceived task may flatter the teaching impact of the entire method. At its best, activity in the discussion develops a student's creativity and independence.

The xTask's idea development area differs from traditional discussion areas in two ways. Messages can be read either linearly grouped in a sequence according to time by pressing linear-button presented in Figure 29, or in tree structures by the content of the messages (intended gray bars on Figures 29). Similar features can be found in several Web-based learning environment, but in many environments the tree structure is the only presentation form for discussion. Moreover, what is written in the xTask discussion area can be summarized by selecting suitable comments and the user can make a desired summary of the content of the entire discussion. This method operates, for example, when the ideas of the groups compete. This summary tool is an attempt to develop a discussion area into a process-oriented working tool.

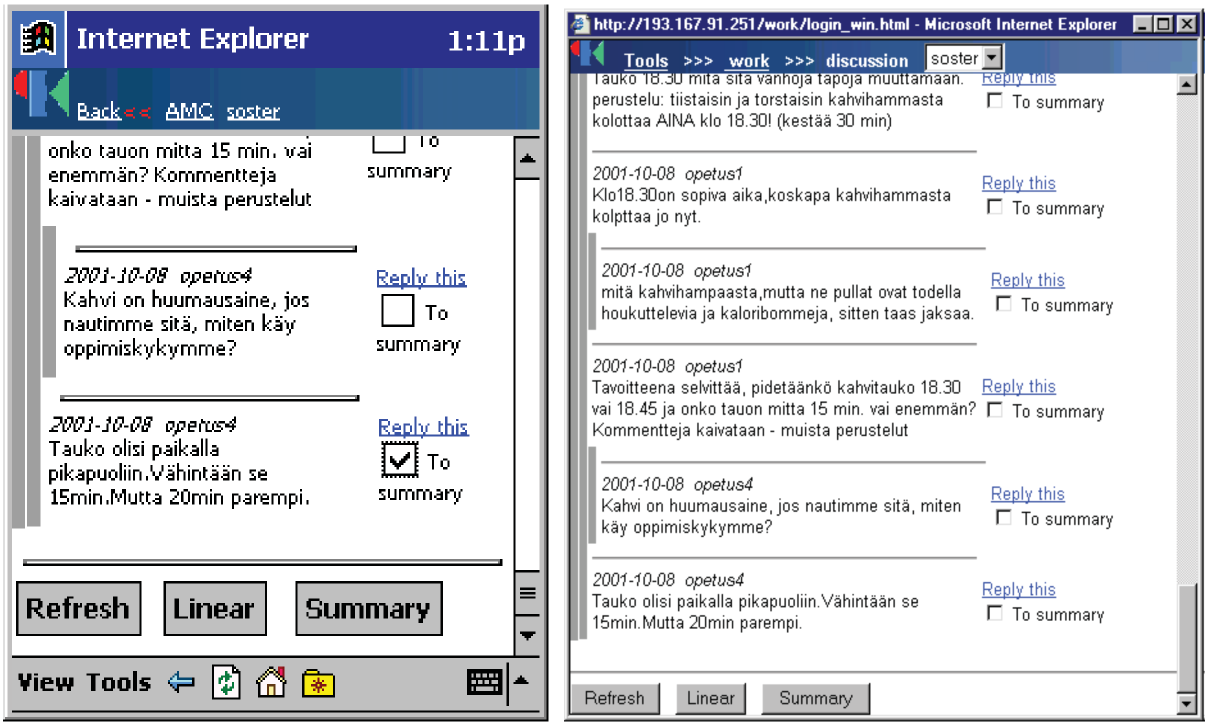


Figure 29. Idea development area on a PDA screen (left) and PC screen (right).

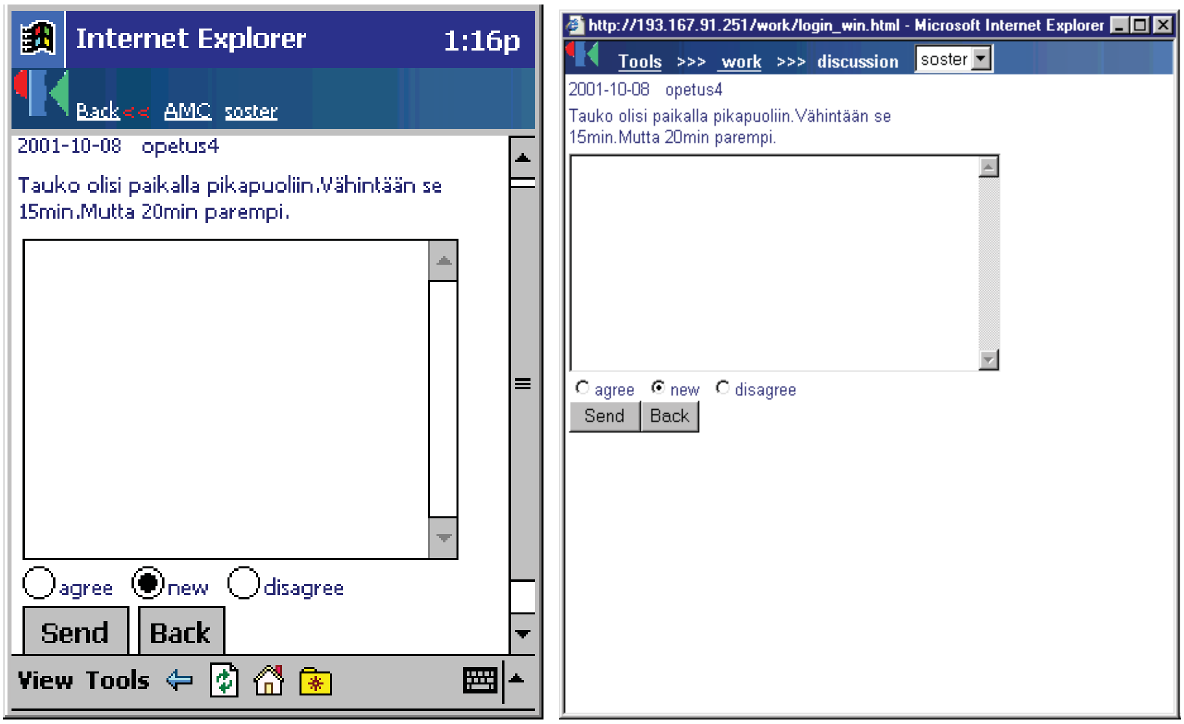


Figure 30. Sending new messages to idea development area (PDA left, PC right).

The navigation in the idea development area is not optimal according to results from Chapter 4. There are scrolling bars used when the text length is bigger than screen. This makes a PDA version of the idea development area slightly slow to use. Paging the text is not a solution in this case: The tree structure would not remain in the paged text.

Also, using navigation elements in the idea development area was not clear. Especially with Communicator those elements were difficult to access and therefore Communicator users mostly read the text only with that device and wrote the texts with PC's. Similar phenomenon does exist among iPaq users, but in their case the attitude towards reading was because of the poor iPaq keyboard.

The technical implementation of the idea development area is described in Figure 31. The idea development area is not one module. It is based on four basic modules, which are operating directly under the xTask shell. The default module is 'a Read Forum x in tree mode' module which is loaded at the beginning every time. The default module, as well as other modules, adds all the information that the user interface needs to call from other modules.

The three modules, 'Read Forum x in tree mode', 'Read Forum x in linear mode', and 'Get summary', only reads the forum database. The fourth module, 'Add comment z after comment y which is in forum x', adds content to the forum database (Figure 30). The 'connection rules' database is a read-only database, which is created at the same time with the forum entity. It includes user managing rules and information for accessing the forum in order to add a comment or get a summary.

The 'Read Forum x in tree mode' displays the discussion in the directed graph, which is meant to find out the structure of the discussion and the structure of an individual issue within the discussion.

The 'Read Forum x in linear mode' displays the messages ordered by time. This mode is designed to help to find and understand the changes within the discussion in time, for example to see how opinions have developed through the discussion.

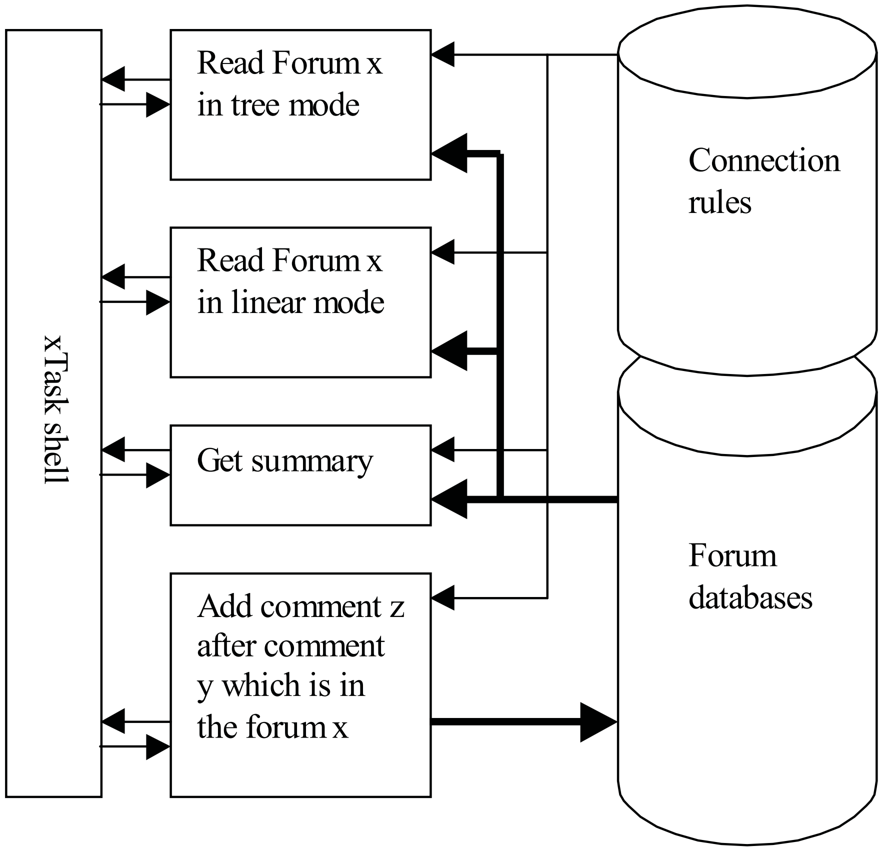


Figure 31. The structure of the idea development area.

The ‘Get summary’ module displays the user-selected comments to one document which can be transported to any other text editor by utilizing the device’s clipboard. The adding module manages new comments and adds them to the database structure.

6.2.5 Document development area

The document development area represents a new attempt to make a program that combines the best aspects of both a discussion area and text processing from a learning perspective into an efficient whole. There is no similar tool in well-recognized Web-based learning environments. The document development area comprises three operational areas: print overview, work overview, and an archive of replaced sections.

The document development area is comprised of sections that can be added, edited or shifted from one place to another (Figure 32, left). The smallest cell that can be worked on is a paragraph (Figure 32, right). In the document development area each user can work on each paragraph without restrictions. Sometimes however, it may happen that two users make changes to the same cell or paragraph. In this case the first stored paragraph will be entered at the desired point and those to be stored later will be entered after the first one with an alert sign. The alert sign informs that there has been overlap in the editing process.

On the right hand side of the document development area there are links to earlier versions of the paragraph (Figure 32, left). By clicking the date a user can read earlier versions. This helps the user to note the changes made over time, which enable the user to assess the development of his/her own thoughts. In the terms of Hakkarainen and al. (1999), the intention of the document development area has been to render the writing process partially transparent. By seeing the development in the text the students can also see the changes of their thoughts in a concrete way.

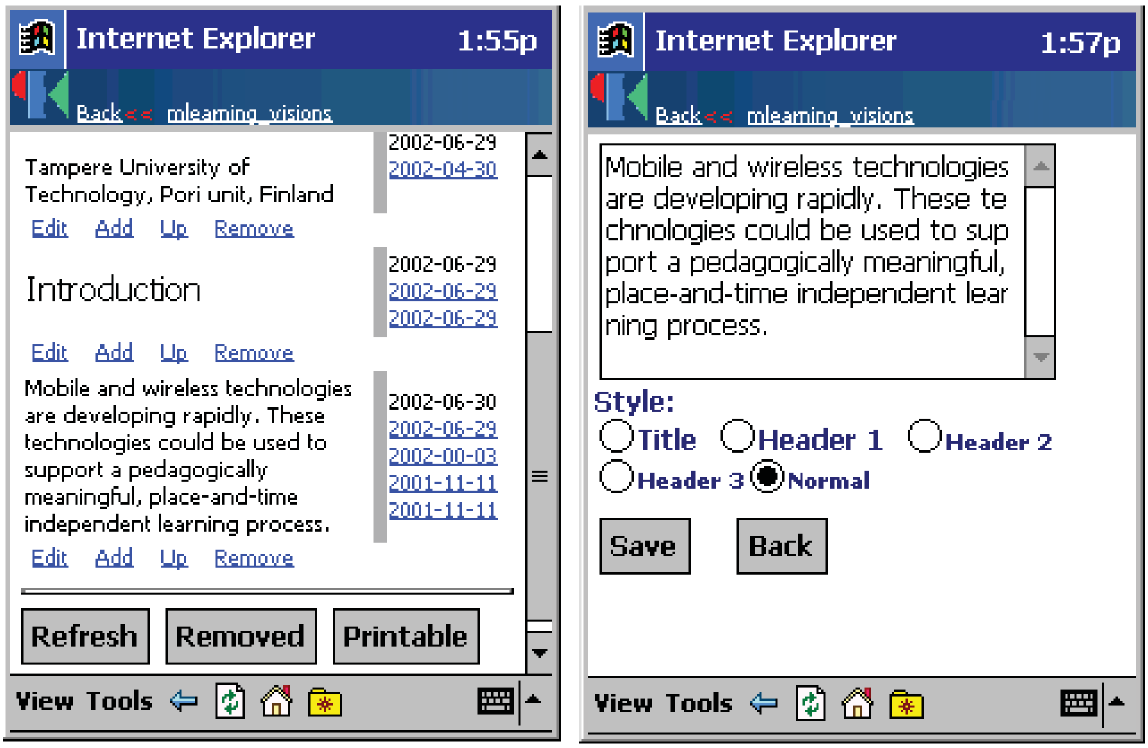


Figure 32. Document development area on a PDA screen (document editing on the right).

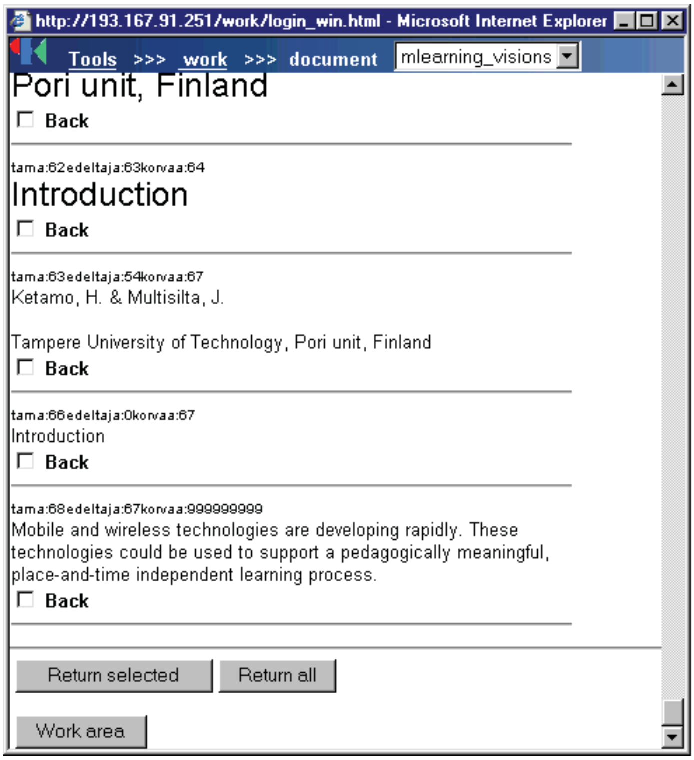


Figure 33. Document development area on a PC screen (removed paragraphs).

In the light of learning theories allowing all thoughts to be written openly promotes more profound learning (Hakkarainen & al. 1999). The development of documents operates just like a simple text processing program in which there may be several users simultaneously on the net. The user is able to modify the document bit by bit. After modifying a section the new version remains as part of the active document, but all old versions remain in the archive (Figure 33), from where they can be returned into document if needed. All users with the right to write in the document can modify and add pieces without restrictions. Simultaneous modifications of the same piece will be made active parts of the document, but a note will be added indicating that they concern the same piece.

When focusing on the document development area in the terms of a usability study in Chapter 4 we can point out several obstacles: Firstly, the document's length increases almost immediately so much that scrolling bars appear on a PDA's screen. This naturally lowers the readability of the written text.

The idea of processing the text in short paragraphs was felt to be a good idea. The texts could be accessed with PC's and PDA's which was the major difference when this document development area was compared to web-based file sharing environments such as BSCW. Even the Communicator users gives positive feedback for the idea:

> *”Though there are several functional difficulties in xTask, I like the idea of document development. When comparing document development in xTask to most web-based document sharing programs editing was easier and faster because of the light text-based editing system.”*

One of the biggest obstacles from the user point of view was the lack of feedback. When users modify the texts there were no “OK” signs for successful operations. The area just opened again with modified content. This kind of problem was mentioned by a few students.

> *”xTask does not give any feedback. This is a real problem from the usability point of view. At least some feedback after operations should be given to the user.”*

The technological implementation of the idea development area is described in Figure 34. Following the structure of the idea development area, the document development area consists of more than one module. The document development area is based on seven modules that are operating under the xTask shell. The modules can operate also without the xTask shell. The default module is the ‘Read document X’ module which is loaded at the beginning. The default module, as well as other modules, adds all the information that the user interface needs to call from the other modules.

The modules (Figure 34) ‘Read document X, and ‘See the deleted paragraphs of document X’ are the constructors for the working display. They only read the database and create the user interface for the document according to the ‘connection rules’. The ‘connection rules’ database is a read-only database, which is created at the same time with the forum entity.

The ‘Create new paragraph in document X after paragraph Y’ gives a blank text editor view of a document after paragraph Y. When the user saves his or her writing, the module saves the information into a ‘documents database’. The ‘Modify paragraph Y in document X’ module gives a text editor view of the requested paragraph. The user can modify the paragraph and save the modifications. The older version of the paragraph will be stored in the removed paragraphs area. If two operations (for a new or edited paragraph) focus on the same place at the same time or the linking has changed before saving, the module reorganizes the database and makes both of the new modifications active.

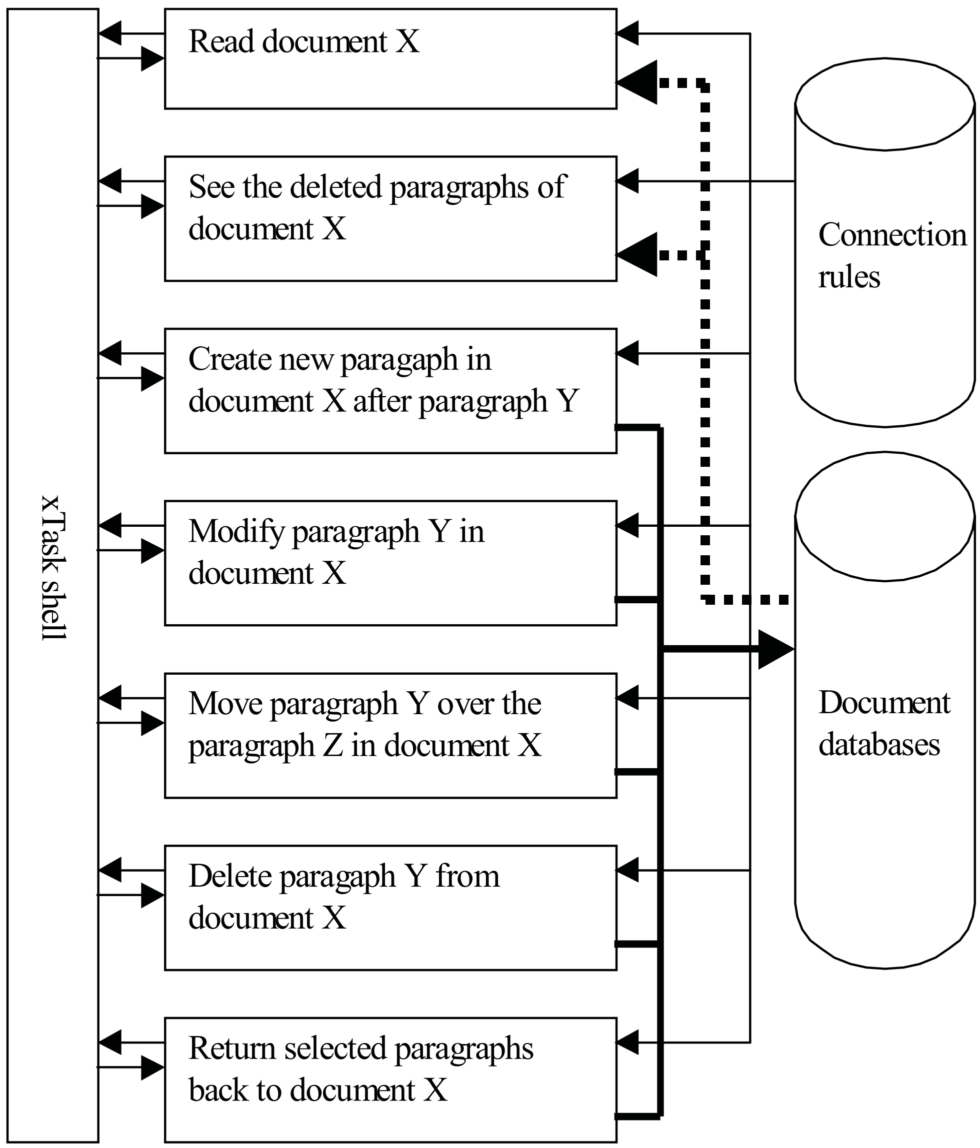


Figure 34. The modules and their relations in the document development area.

The ‘Move paragraph Y over paragraph Z in document X’ module switches the places of two paragraphs. It also ensures that the linking between the other paragraphs (paragraphs before and after, as well as older and removed paragraphs) would not change in an unwanted way. The ‘Delete paragraph Y from document X’ module deletes the requested paragraph and stores it in a removed paragraph area. It also manages the linking corrections.

The ‘Return selected paragraphs back to document X’ module returns the selected paragraphs back to their places within the active document. If their place can not be traced because of major changes within the document, they are returned to the end of the document. After the paragraphs have been returned, the user can place them according to preference using the ‘‘Move paragraph Y over the paragraph Z in document X’ operation.

The document development area can be used as a module for another system. There are only the same limitations that were presented within the idea development area.

6.3 Evaluation of xTask

The empirical study was modeled to be a course about mobile terminal usability. The study was carried out during May 2002. There were ten students of which two were females participating in this course. The students were at least second year students, between 21 and 50 years of age. The students were divided into three work groups so that in group 1 there were two males and two females, in groups 2 and 3 there were three males.

All the students in this course were given a mobile device for their use during the course. Six students used Nokia Communicators (in groups 1 and 2) and four students used Compaq iPaq (one in group1 and three in group 3). For Communicator users there were GSM-Data connections (9600bps) and iPaq users were connected to university’s WLAN (max. 11Mbps, min. 1Mbps). WLAN could only be used at the university, so they could not use their mobile devices during their free time.

The workgroups were asked to accomplish several tasks (text-based reports) with two specific xTask tools: idea development area and document development area (described in Chapter 6.2). The course tasks were described in the xTask’s library. There were also hyperlinks to web materials on usability and mobility in order to fulfill the needs of the students when doing their tasks. In this study the tasks in the course don’t have an important role, so they are not described. The empirical analysis of this study focuses on the working processes and quantitative elements of work.

The students had only one face-to-face lecture before real group work begun. In the lecture, the students were asked to do all the work with mobile terminals or with PC computers (at home or at university). The students were allowed to choose freely which platform they would like to use. In fact they were encouraged to try both mobile and PC platforms to determine which one they preferred. Face-to-face group work was not allowed. According to log information there was no face-to-face working, or at least the students were clever enough to logon from only one client at a time.

In general, all groups did good work during the course. Because the goals of the course were quite open and the learning results are not important for this analysis, only high level evaluation is given here. Group 1 did excellent work. Both quality and quantity were high. Groups 2 and 3 did good work also: The quality of their work was high, but for them the quantity was not as big as it was with Group 1. On average, individual students worked 30-50 hours in this course.

Because of the small number of participants in the course (n=10) the results can not be discussed using statistical analysis. Only means and frequencies are reported. The analysis is mostly done with qualitative methods according to information in system databases and student interviews. Interviews with the students are used within the text to give a deeper view into specific issues. The original interviews were done in Finnish.

6.3.1 Platform adaptation from the user point of view

The students used both PC's and PDA's during the course. The PC platforms of students used during the course were not controlled. PDA platforms were given to students in the following way: Group 1 had three Communicator users and one iPaq user. In Group 2 all students used Communicators and in Group 3 all students used iPaqs.

In Figure 35 relative PDA use is described as a percent of all use. The use in this case describes the number of HTTP requests, because it was easy to record all the requests and the platforms from which the request was made. Used time was not even attempted to record, because through HTTP we can only estimate the time used. Both reading and writing operations are included in these numbers. Reading and writing operations were not recorded separately, they are solved by interviewing the users.

Group 1 and Group 3 used PDA's approximately in 25% of their work. Group 2 instead used PDA's in only 8% of their work. The use of PDA's does not explain anything about the results of group work. All groups did good work, especially Group 1, but still there are great differences in PDA use between Group 1 and Group 2. On the other hand, Group 1 and Group 3 used PDA's quite as much, but there were differences in their results.

The only issue we can say about PDA use is that those two (persons in Group 1 and in Group 3) who had a remarkably high percentage (approximately 40%) of PDA use, did shorter texts than others, but they also did these texts more often. So the total amount of text was quite similar for all students inside the group. On the other hand, those two students (both in Group

2) who had a significantly low percentage of PDA use (approximately 4%), did longer texts than others.

According to this, we can assume that those who prefer to write short texts used PDA’s more often and those who prefer to write longer texts used PC’s. This probably is dependent on the poor keyboards of PDA’s, but we can not forget the results on readability from Chapter 4. Those who prefer to write longer texts might also want to focus on text in different ways than others. For them the poor readability of PDA’s might be another reason why they prefer a PC platform.

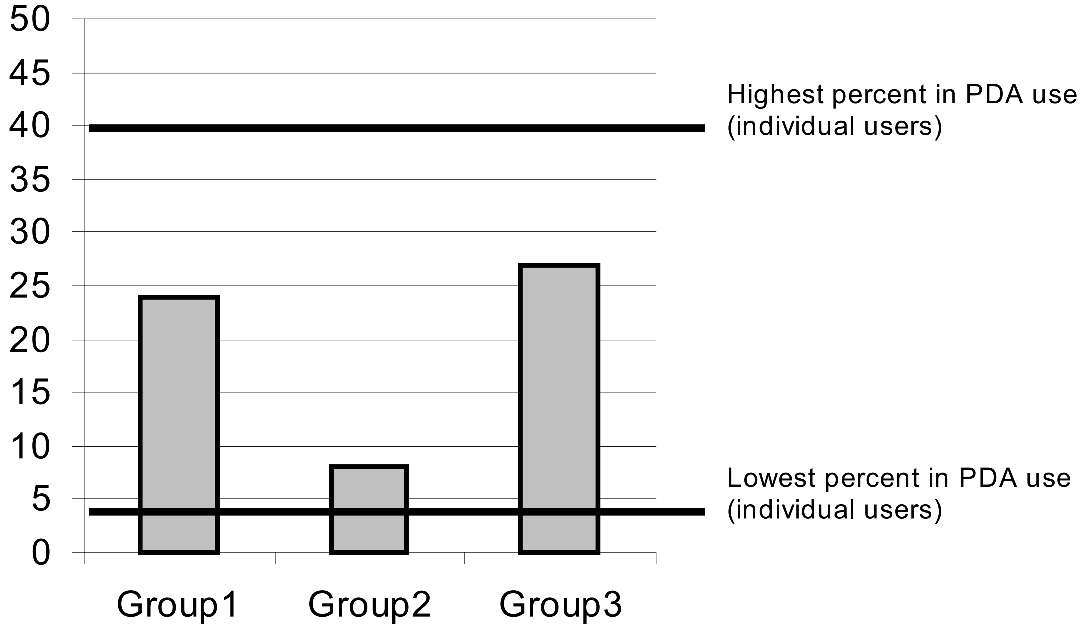


Figure 35. Relative amount of PDA use.

For some students the technical problems were a reason why they did not use PDA’s as often as they might have wanted. The GSM networks were criticized quite a lot.

The Communicator users thought that WLAN would be better than the GSM network. That is probably right, but WLAN users criticize that they would have used PDA’s more often if the network had been more available. After all, network speed is one obstacle that should be taken into account when designing platform adaptive systems for mobile devices.

All students felt that mobile devices are not ready to be the only platform for studying. They still prefer PC’s with wired networks, but admits that PDA’s can be used to support studying. From a platform adaptive systems point of view this can be seen as follows: 1) Not all the tools and features need to be implemented for mobile terminals. 2) PDA's can be used for reading more easily than for writing – it is possible to implement only reading features for mobile devices. In xTask the reading features for PDA's would be enough for users. Technically this would also give more freedom to improve the navigation of the PDA versions of the tools.

6.3.2 Group dynamics as a background for future behavior adaptation

In this chapter group dynamics and work processes are used as a background when defining possibilities for user behavior adaptation in xTask. The analysis is carried out with quantitative methods and it focuses on group work in the terms of Drucker's theory.

Drucker (1999) has presented the key factors for successful eWork. These factors also describe well the factors of successful eLearning: 1) the nature of the work, 2) autonomy, 3) creativity, 4) continuing learning, 5) quality, and 6) commitment (Drucker 1999; Ruohonen 2001). Though all this can be said as 'performance is only about ability and motivation' (Kelloway & Barling 2000), the approach still gives good background for evaluating working processes in a digital environment. From this perspective we assume that autonomy, creativity, and commitment are the key factors for successful group work.

Autonomy, or independence, includes ability to act in a purposeful manner without external supervision or guidance. Decision-making in groups, flexible working arrangements, and equal dissemination of information without hierarchical censorship have been found to be good approaches for supporting autonomy in work groups. (Jimenez 2001; Fulton & al. 2001).

In this study, the elements of autonomy could be clearly seen: All groups reached their goals and all students participated in work without any external supervision. The groups themselves supervised its members. The lack of the leadership was seen as a problem for some students.

> *"There was no leader in our group. That is why our work was not as organized as normally."*

Most of the students felt that the leadership can be also shared by creative use of the idea development area or by using some other forms of communication.

”Our group work was optimal in this context. Of course there were possibilities for developing our actions: For example we could use the idea development area to plan the work more carefully.”

”In our group everyone had their own goals. If we could sit down and plan our work better, the results would have also been better.”

One possible improvement is to introduce a voting or evaluation tool to xTask. With such a tool students could decide if the discussion is finished or if the section in the document is ready. This itself is not a user behavior adaptive extension, but when continuing ideas it can be developed into such: When some element has reached a critical value, the system marks it as ready (makes it also read-only). So the work is lead by collaborative decision-making and it is supported by a system that adapts to this new decision. With this kind of tool requested leadership could be easily done in groups.

An other solution to support the decision-making is to combine document development area and idea development area into a new area in which every Chapter can be discussed and all the structure for document development can be planned by the help of the idea development area. There is also space for user behavior adaptation: If the system observes that some document do not find a focus the system encourages the group to discuss the work first. Naturally finding rules for his kind of adaptation is difficult.

One approach for finding rules for this is to study the similarities between the replaced paragraphs: if there are great differences between replaced paragraphs we can assume that the document had not found its focus. If the differences between paragraphs are small we can assume that modifications are only to improve the quality of the document not to find the focus.

Creativity is also one of the keys to success in eLearning. In fact, creativity is said to be a key issue in all kinds of collaboration (Riel 2000). The basic premise of creativity is the ability to assess former activities in relation to results and thereby find a new direction for activities (Mezirow 1995). Creativity can be examined as being the ability to act individually and effectively in a new and surprising situation (Ahuja 2001). There is no place for creativity in a tightly formulated activity, thus creativity should be cultivated and researched in connection with problems of an essentially open nature.

Since discussion in an online environment is quite different from conventional face-to-face discussion (Marttunen 1997), new features of discussion and co-operation may arise. Dowling

(2000) suggests that all behavior even in virtual worlds differs from behavior in the real world. In the virtual worlds different types of communication skills are required.

In this study one successful form of work processes has been clearly pointed out: All work in groups started with encouragement. In most cases a few try to start the work, but only with good encouragement can the work really begin.

Encouragement naturally needs creativity: the encourager should guess what the key elements of the issue are and how to motivate the group to reach their goals. Encouragement also requires independence: The encourager should be a very independent person in order to direct the focus of the group in some direction. In general the encourager can be seen as a non-formal leader of the group. For example, the following encouragement started a good working process in this study:

> *"I think we should focus on defining 'usability'. According to Nielsen usability includes a) the ability to learn b) affectivity c) the ability to remember d) lack of mistakes and e) visual outlook. How do you understand these concepts?"*

The process continues with following replies (only the beginning of the answers are documented):

> *"Good start, K... Here are few comments: Ability to learn and ability to remember are close to one another. They can be supported by using familiar metaphors…"*

> *"I think that affectivity can be measured by summing a) and b). Mistakes lower the user's trust toward the pages, so usability lowers a lot…"*

In this process the encourager gives a classification that serves as background for later work. Another, more open, process about the same issue starts with:

> *"Yes, that was an interesting point of view, but say, what issues can we discuss under the concept of usability?"*

The response was:

> *"I think that usability is a complex issue. First we should decide for what purpose we are creating these definitions of usability…"*

“I think that usability is an instrument for describing the properties of an interactive system: How can the user utilize the system…”

This kind of process lead to commitment to work, which itself can be seen as a goal for this kind of studying: One basic condition of commitment is that the student feels that his or her investment of time will yield some intellectual capital for himself or herself. By supporting meaningful and challenging discussions the group can motivate its members.

From a user behavior point of view this can be seen as one approach to improving the xTask environment. In all cases successful working processes began with encouragement. Without encouragement the processes did not start. There were only individual comments without real collaboration. The user behavior adaptive group work agent could observe the discussions and if there was no real collaboration, the agent offered successful encouragement (taken from an other group). The implementation of observing collaboration would be challenging. There might be some relations and semantic similarities between successful processes, which could be found by observing the collaboration processes carefully.

The adaptive agent for encouraging the group should itself fulfill the above mentioned requirements of successful collaboration: independence, creativity and commitment. Commitment is not difficult to implement, but independence and creativity are quite challenging.

7 Conclusions

The conclusions of the thesis are presented from both platform adaptive and user behavior adaptive points of view. Both chapters include short summaries of the empirical results. These results were evaluated in order to point out the general findings of the thesis.

7.1 Platform adaptation – focus on user

When comparing different technology platforms (Chapter 4), the biggest result is that PDA's can be used quickly from a human-computer interaction point of view. Technological usage of PDA's is also fast to learn. In spite of experience in playing computer games, only a few PC users, who used a traditional mouse, reached the average PDA user's pointing speed. The PC with a touch screen was not as fast to use as a PDA. This indicates that a touch screen is fast only when movement of the hand is limited and the user can see the whole screen without moving his or her eyes.

Readability in PDA platforms was poor. This was probably due to the text scrolling system of the test, which was not optimal for reading. Maybe some kind of page turning mechanism would have been better for the PDA test. Readability in the PDA platform could also have been poor because of the low resolution of the screen: the picture or text on the screen of the PDA device was not sharp enough to present pictures or text in an 8pt or a smaller font. This led to a situation in which the information could not be presented effectively on the screen: When comparing the character size to the distance of the screen and the user's eyes the characters were too large and the column was not optimal for reading.

When combining these results, we can say that PDA's and PC's can not be used equally in situations. While PDA's are fast to use, PC's are better when reading. Similar results were found from the empirical study of xTask (Chapter 6). Users felt that PDA's were fast to use, but they still preferred PC's when writing texts. PDA's were mostly used for reading texts and giving short comments. That was because the screen size of PDA's was not large enough for reading and the keyboards on PDA's were far from optimal for writing. According to these results we might even be able to say that recent PDA's can not replace PC's in work and education. When the limits of a PDA's screen, keyboard and network connections are fixed there might be more opportunities for applying PDA's in training and education.

This does not mean that PDA's are always a worse alternative than a PC for work and education. In the Adaptive Geometry Game (Chapter 5) the PDA was found to be an optimal platform for that kind of use. In the Adaptive Geometry Game all the user interactions were similar to the interaction in the pointing test (Chapter 4). Shorter user interaction times made the Adaptive Geometry Game even more reliable: Pointing speed did not affect the observed recognition speed as much as it would affect the speed in a mouse environment and therefore adaptation logic got more reliable observations for decision-making.

There was also another feature that was essential for the successful PDA version of the Adaptive Geometry Game: The whole user interface could be placed on a PDA's screen without any need for scrolling. This also kept the pointing times short when the user could see all the navigation elements at once. Because of the easily and quickly used environment the Adaptive Geometry Game was successful.

A combination of these results indicates that when designing platform adaptive systems the focus should be on the user, not on the technology. Technologies for platform adaptation are fairly easy to use, but user behavior in the platform is the key issue for successful platform adaptive solutions.

The key questions before starting to design platform adaptations for a PC and a PDA environment might be: 1) What are users supposed to do with the environment? 2) Why would users do that with both platforms? 3) Is it possible to create a limited set of platform adaptive features? 4) How can we know what the most used features are that should be made to be adaptable?

These questions can be answered easily in the context of the Adaptive Geometry Game: Users were asked to point out the polygons. Both platforms might be meaningful for use because, if a PDA is available it is faster to use than a PC, and according to pupils' opinions, PDA's are more interesting than PC's. When PDA's are not available PC's are the natural choice for playing the game. In the Adaptive Geometry Game all of the features should made to be adaptable. Because the game was developed to use with pointing operations and there was no need for scrolling, it could easily be converted into different platforms.

The same goes for most educational games for young pupils: If user interface could be implemented so that there is no need for scrolling (popup menus could be naturally used) and input giving is meaningful with a mouse or touch screen, it might be worthwhile to make a PDA and PC platform adaptive version of the game. When the user can point to the navigation elements with reasonably good speed the game might be easy to play. Of course we should remember that there are no PDA's in schools and therefore commercial software production for a PDA platform is not meaningful.

For xTask these previously mentioned questions are not so easy to answer. First of all, students should be able to work in groups within the environment. The question about why the students would use both platforms can be approached in the terms of mobility. Students might want to participate in courses when they have time. Afterwards, the limited set of platform adaptive features might have been enough to support the need for mobility. According to empirical results all the features were not used in a PDA environment because of the poor usability of the device and xTask, and because of slow GSM networks. For example, all writing operations in the document development area could be excluded from a PDA interface. Writing operations for discussions were used in PDA's so they should be included. Several possibilities for develop xTask were found during the empirical study.

The fourth question is challenging in terms of software development. In the xTask case we found some ideas from the empirical study, but for a software developer this means that more empirical user behavior tests should be done before the product can find its focus. For platform adaptive systems all the user interfaces should be tested. Also traditional usability studies are not enough for platform adaptive systems. Utilization processes are as important as usability itself.

In fact, we could say that a successful platform adaptive system is based on a careful study of user behavior in target platforms. Technological quality itself is not enough.

7.2 User behavior adaptation – focus on observation

The Adaptive Geometry Game (Chapter 5) seemed to work well. Over 60% of the pupils reached the higher skill group after playing the game. What is more important, all the low skill pupils reached average skills in geometry after playing the game.

The small sample (n=17) naturally lowers the significance of these results. On the other hand, the results achieved were quite clear. As a matter of fact, the results were not even meant to describe the general properties of the learning materials, but only to fulfill the needs of this study. When transferring these ideas to other learning games, the factors and the limits of the adaptation system should be examined from the departure point of the learning material. In general, these results are quite promising for finding more general rules for optimizing learning results according to the interactions of users.

The rules for optimizing learning outcomes were found with careful observation of learning situations in the first stage of the study. In that study, all the interactive learning materials gave good learning outcomes. The learning outcomes can be explained by combining the pointing speed of users and the number of errors during the game. The adaptation rules for the Adaptive Geometry Game were developed according to these results. There were many more observed variables than were finally needed for the adaptation rules, but without observing them all, we could not have been sure that the most useful variables would be used in the user behavior adaptive game. In addition, if we somehow could guess the correct variables to observe we hardly could guess how to utilize them for decision-making.

This can be seen as a challenge for software development: When developing user behavior adaptive systems the focus of research should be on the elements or factors that are to be observed and used in the system. If we (or the exact program in the adaptive system) do not observe the right and meaningful factors, we can be sure that the user behavior adaptation is doomed to fail. The same goes for behavior adaptive systems that are using relational or neural networks as the mathematical model. If the recorded data does not describe the key factors of the phenomenon it is useless for the adaptation. Naturally neural network systems can be taught to understand recorded data, but if there are no the optimal factors in the data the optimal behavior adaptation can not be found.

When focusing on observed data in the context of the readability study (presented in Chapter 4), we found out that young people behave impulsively in digital environments. It seems that people over 16 years have learned to think more reflectively than people under 16 years of age, and thus they behave in a more reflective way in digital environments. What is more, the impulsive behavior of young people easily transfers into reading styles and makes the results of reading the digital texts less than satisfactory.

If we had observed only pupils aged less than 16 years and if we had found some rules to improve pupils' reading despite their impulsive reading style, we still could make the wrong choices in terms of learning. Although those pupils need adaptive support for their reading such an adaptive tool could harm the natural development of their reading skill. That assumption can be based on the reading style of older people: They might have been impulsive readers when they were young, but the reading style had naturally improved over time.

The paradox within reading style development leads us to an uncertain situation: Is it always necessary to support or develop current behavior? In this case probably not, but this can not be transferred to any other situation.

After all, this means that it is not enough to observe some factors of the phenomenon that should be learned. The factors should be observed as widely as possible, even though it is certain that most of them are unnecessary.

8 References

Ahituv, N., Jehiel, Z. & Machlin, I. (1997). Environmental Scanning and Information Systems in Relation to Success in Introducing New Products. Information and Management, vol 33, p. 201-211.

Ahuja, S. (2001). Functional Integration Through Alternative Officing: Participative Strategies for Creating Suitable Structures. In R. Suomi (ed.). Proceedings of t-world 2001: The 8th European Assembly on New Ways to Work, Helsinki 12-14.9.2001, p. 3-18.

Albrecht, F., Tiller, T. & Koch, N. (1999). Making Web-Based Training More Efficient. Paper presented at LWA'99: Lernen, Wissensentdeckung und Adaptivität – ABIS'99: 7ter Workshop Adaptivität und Benutzermodellierung in Interaktiven Softwaresystemen. Magedeburg, Germany, [http://pst1.pst.informatik.uni-muenchen.de:8080/ - read 10/2001].

Arnes, Y., Miller, L. & Sondheimer, N. (1998). Presentation Design Using an Integrated Knowledge Base. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 131-139.

Aude, D. (2000). ExploraGraph: Improving interfaces to improve adaptive support. In Proceedings of the International Workshop on Adaptive and Intelligent Web-based Educational Systems, held in Conjunction with ITS 2000, Montreal, Canada, p. 102-111.

Billsus, D., Pazzani, M. J. & Chen, J. (2000). A learning agent for wireless news access. Proceedings of 2000 International Conference on Intelligent User Interfaces, New Orleans, USA, p. 94-97.

Bollen, J. & Heylighen, F. (1996). Algorithms for the self-organisation of distributed, multi-user networks. Possible application to the future World Wide Web. [http://pespmc1.vub.ac.be/papers/SelfOrganWWW.html – read 10/2001].

Bolt, R.A. (1998). 'Put-That-There': Voice and Gesture at the Graphics Interface. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 19-27.

Brusilovsky, P. & Pesin, L. (1994). ISIS-Tutor: An Intelligent Learning Environment for CDS/ISIS Users. In Proceedings of CLCE'94. Joensuu, Finland, [http://cs.joensuu.fi/~mtuki/WWW_clce.270296/Brusilov.html – read 1/2002].

Brusilovsky, P., Schwarz, E. & Weber, G. (1996a). ELM-ART: An intelligent tutoring system on World Wide Web. In C. Frasson, G. Gauthier & A. Lesgold (ed.). Intelligent Tutoring Systems (Lecture Notes in Computer Science, vol 1086). Berlin: Springer Verlag, p. 261-269, [WWW.contrib.andrew.cmu.edu/~plb/ITS96.html – read 1/2002].

Brusilovsky, P., Schwarz, E. & Weber, G. (1996b). A Tool for Developing Adaptive Electronic Textbooks on WWW. In Proceedings of WebNet-96, [WWW.contrib.andrew.cmu.edu/~plb/WebNet96.html – read 1/2002].

Brusilovsky, P. & Cooper, D.W. (1999). ADAPTS: Adaptive hypermedia for a Web-based performance support system, Proceedings of Second Workshop on Adaptive Systems and User Modeling on WWW at 8th International Word Wide Web Conference and 7-th International Conference on User Modeling, Toronto and Banff, Canada. Computer Science Report 7/99, Eindhoven University of Technology, p. 41-47.

Brusilovsky, P. (2001). Adaptive Hypermedia. User Modeling and User-Adapted Interaction, vol 11, p. 87-110.

Buchanan, T. & Smith, J. (1999a). Using the internet for psychological research: personality testing on the World Wide Web. British Journal of Psychology, vol 90, 1/99, p. 125-145.

Buchanan, T. & Smith, J. (1999b). Research on the internet: Validation of a World Wide Web mediated personality scale. Behavioral Research Method, Instruments, & Computers, vol 31, 4/99, p. 565-571.

Carro, R.M., Pulido, E. & Rodriguez, P. (1999a). Object Orientation in the TANGOW System: Working with Dynamic Task Trees. In Proceedings of Argentine Symposium on Object Orientation, ASOO'99. Buenos Aires, Argentina, p. 35-46.

Carro, R.M., Pulido, E. & Rodriguez, P. (1999b). An Adaptive Driving Course Based on HTML Dynamic Generation. In Proceedings of WebNet'99. Hawai, USA, p. 171-176.

Chi, M.T.H. & Bassok, M. (1989). Learning from examples via self-explanations. In: L.B. Resnick (ed.). Knowing, learning, and instruction. Essays in honor of Robert Glaser. Hillsdale, NJ: Lawrence Erlbaum, p. 251-282.

Chin, D.N. (1998). Intelligent Interfaces as Agents. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 343-357.

Clement, J. (2000). Levels of causal knowledge in solving explanation problems in science. Paper presented in AERA2000, New Orleans, USA, 24.-28.4.2000.

Clements, D.H. & Battista, M.T. (1992). Geometry and spatial reasoning. In: D.A. Grouws (ed.). Handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics. Reston, USA: NCTM, p. 420-464.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. Educational Researcher, vol 23, 7/1994, p. 13-20.

de Jong, T., Ainsworth, S., Dobson, M., van der Hulst, A., Levonen, J., Reimann, P., Sime, J-A., van Someren, M.W., Spada, H. & Swaak, J. (1998). Acquiring Knowledge in Science and Mathematics: The Use of Multiple Representations in Technology-Based Learning Environments. In M.W. van Someren, P. Reimann, H.P.A. Boshuizen & T. de Jong (ed.). Advances in Learning and Instructional Series: Learning with Multiple Representations. Oxford, UK: Elsevier Science Ltd, p. 9-40.

Dobson, M. (1998). Toward Decision Support for Multiple Representations in Teaching Early Logic. In M.W. van Someren, P. Reimann, H.P.A. Boshuizen & T. de Jong (ed.). Advances in Learning and Instructional Series: Learning with Multiple Representations. Oxford, UK: Elsevier Science Ltd, p. 87-101.

Dowling, C. (2000). Social Interactions and the Construction of Knowledge in Computer-Mediated Environments. In D.M. Watson & T. Downes (ed.). Communications and Networking in Education: Learning in a Networked Society. Massachusetts: Kluwer Academic Publishers, p. 165-174.

Dowling, C. (2001). Agent Technologies and the Electronic Classroom – Some Research Issues. Paper presented at WCCE 2001 – 7th World Conference on Computers in Education. 29.7.-3.8.2001, Copenhagen, Denmark.

Drucker, P.F. (1999). Knowledge-Worker Productivity - The Biggest Challenge. California Management Review, vol 41, 2/1999, p. 79-94.

English, L.D. & Halford, G.S. (1995). Mathematics education, models and processes. Mahwah, New Jersey, UK: Lawrence Erlbaum associates.

Espinoza, F. & Höök, K. (1996). An interactive WWW interface to an adaptive information system. Paper presented at 5th International Conference on User Modeling. [WWW.sics.se/~kia/espinoza_hook.html - read 1/2002].

Fleming, J. (1998). Web Navigation, Designing the User Experience. Sebastopol, CA: O'Reilly & accociates, Inc.

Fulton, C., Halpin, E.F. & Walker, S. (2001). Privacy Meets Home-based eWork. In R. Suomi (ed.). Proceedings of t-world 2001: The 8th European Assembly on New Ways to Work, Helsinki 12-14.9.2001, p. 31-42.

Gabrielli, S., Rogers, Y. & Scaife, M. (2000). Young Children's Spatial Representations Developed through Exploration of a Desktop Virtual Reality Scene. Education and Information Technologies, vol 5, 4/00, p. 251-262.

Garner, R., Alexander, P., Gillingham, M., Kluowich, J. & Brown, R. (1991). Interest and learning from text. American Educational Research Journal, vol 28, 4/91, 643-659.

Giardina, M. & Oubenaissa, L. (2001). Distributed Cognitive Tools to Improve High Order Cognitive Skills such as: Argumentation, Negotiation and Restructuring of Knowledge. In Proceedings of ED-MEDIA 2001, p. 584-586.

Hakkarainen, K., Lonka, K. & Lipponen, L. (1999). Tutkiva oppiminen. Älykkään toiminnan rajat ja niiden ylittäminen. WSOY: Helsinki.

Halasz, F. & Schwartz, M. (1994). The Dexter Hypertext Reference Model. Communications Of the Acm, vol 37, 2/94, p. 30-39.

Hall, V.C., Bailey, J. & Tillman, C. (1997). Can student-generated illustrations be worth ten thousand words? Journal of Educational Psychology, vol 89, 4/97, p. 677-681.

Harp, F. & Mayer, R.E. (1998). How seductive details do their damage: A theory of cognitive interest in science learning. Journal of Educational Psychology, vol 90, 3/98, p. 414-434.

Hasegawa, S., Kashihara, A. & Toyoda, J. (2001). An Adaptive Navigation Support with Local Indexing for Web-Based Learning. Paper presented at WCCE 2001 – 7th World Conference on Computers in Education. 29.7.-3.8.2001, Copenhagen, Denmark.

Hermina, J.M. & Simon, H.A. (1998). One Person, Multiple Representations: An Analysis of a Simple, Realistic Multiple Representation Learning Task. In M.W. van Someren, P. Reimann, H.P.A. Boshuizen & T. de Jong (ed.). Advances in Learning and Instructional Series: Learning with Multiple Representations. Oxford, UK: Elsevier Science Ltd, p. 197-236.

Hetherington, R.G., Kim, J. & Lee, Y. (2001). Distributed Adaptive Learning Systems. In Proceedings of ED-MEDIA 2001, p. 743-744.

Hokanson, B. & Hooper, S. (2000). Computers as cognitive media: examining the potential of computers in education. Computers in Human Behavior, vol 16, p. 537-552.

Hong, H., Kinshuk, He, X. & Patel, A. (2001). Chris Jesshope, Application of Mobile agents in Web-based Learning environment. In Proceedings of ED-MEDIA 2001, p. 778-783.

Hopper, M. (1998). Assessment in WWW-based learning systems: Opportunities and challenges. Journal of Universal Computer Science, vol 4, [http://www.jucs.org/].

Jacob, J.K. (1998). The Use of Eye Movements in Human-Computer Interaction Techniques: What You Look At is What You Get. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 65-82.

Jimenez, J. (2001). Survillance in a Context of Remote Work: the Janus Syndrome, from Trust to Electronic control. In R. Suomi (ed.). Proceedings of t-world 2001: The 8th European Assembly on New Ways to Work, Helsinki 12-14.9.2001, p. 59-76.

Jonassen, D.H. (1994). Computers in the schools: Mindtools for critical thinking. College Park, USA: Penn State Bookstore.

Jonassen, D.H., Reeves, T., Hong, N., Harvey, D. & Peters, K. (1997). Concept Mapping as cognitive learning and assessment tools. In Journal of Interactive Learning Research, vol 8, 3/97, p. 289-308.

Kameas, A., Pintelas, P., Mikropoulos, T.A., Katsikis, A. & Emavalotis, A. (2000). EIKON: Teaching a High-School Technology Course with the aid of Virtual Reality. Education and Information Technologies, vol 5, 4/00, p. 305-315.

Kaufmann, H., Schmalstieg, D. & Wagner, M. (2000). Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. Education and Information Technologies, vol 5, 4/00, p. 263-276.

Kay, J. (2001). Learner Control. User Modeling and User-Adapted Interaction, vol 11, p. 111-127.

Kelloway, K.E. & Barling, J. (2000). Knowledge work as organizational behavior. International Journal of Management Reviews, vol 2, 3/00, p. 287-304.

Kennedy, D. & McNaught, C. (2001). Computer-based cognitive tools: Description and design. In Proceedings of ED-MEDIA 2001, p. 925-930.

Keranto, T. (1997). Kriittinen ajattelu ja tieteentuntemus matematiikan opetuksessa. In: Räsänen, P., Kupari, P., Ahonen, T. & Malinen, P. (ed.). Matematiikka - näkökulmia opettamiseen ja oppimiseen. Jyväskylä: Yliopistopaino, p. 251-268.

Ketamo, H. & Suomala, J. (2000). Possibilities of code-embedded observation in WWW-based learning software development. Proceedings of Measuring Behavior 2000, 3rd international conference on methods and techniques in behavioral research. Nijmegen, Netherlands, p. 185-186.

Ketamo, H., Suomala, J., Alamäki, A. & Vasama, J. (2000). Constructive learning and newmedia. Proceedings of 23nd IRIS (Information systems research seminar in Scandinavia), August 2000, Uddevalla, Sweden, p. 1567-1572.

Ketamo, H. & Multisilta, J. (2001a). Lapset, nuoret ja matkaviestintä (Children, young and mobile communication). Publications of Pori School of Technology and Economics, no 34.

Ketamo, H. & Multisilta, J. (2001b). The xTask - Environment for mobile learning, Press release 11.12.2001, Pori Finland.

Ketamo, H. (2001a). Interaction and learning - Learning results in multimedia geometry game. Proceedings of ED-media 2001, June 2001, Tampere, Finland.

Ketamo, H. (2001b). Vuorovaikutteisten geometrian oppimateriaalien toimivuus esiopetuksessa. Lisensiaattitutkielma, Turun yliopisto. (Interactive Geometry Learning Materials in Pre-School Education, Licentiate thesis, University of Turku.)

Ketamo, H., Multisilta, J., Lahti, J. & Keiho, H. (2001a). Measuring interaction between user and multimedia elements. Proceedings of the 4th international conference on multi-dimensional mobile communications (MDMC'01), June 2001, Pori, Finland, p. 40-45.

Ketamo, H., Multisilta, J., Lahti, J. & Keiho, H. (2001b). xClass - Extensible Virtual Classroom - Mobile communication possibilities in teaching. Proceedings of ED-media 2001, June 2001, Tampere, Finland.

Ketamo, H., Alajääski, J. & Multisilta, J. (2002a). Visions about mobile technologies in elementary education. Proceedings of WCCE2001: The 7th World Conference on Computers in Education. 27.7.-3.8.2001, Copenhagen, Denmark. In press, to be released in summer 2002.

Ketamo, H., Suominen, M., Keiho, H. & Multisilta, J. (2002b). xTask – studying environment to pocket. Paper presented at ITK'02 (Interactive Technology in Education 2002), 17.4.2002 Hämeenlinna, Finland.

Ketamo, H. (2002a). Multimedia learning game in pre-school geometry lesson. Proceedings of CINTEC 2001, July 2001 Aveiro, Portugal, p. 37-44.

Ketamo, H. (2002b). mLearning for kindergarten's mathematics teaching. Proceedings of WMTE 2002 - Wireless and Mobile Technologies in Education Conference, August 2002, Sweden. In press, to be released in summer 2002.

Ketamo, H. (2002c). An Adaptive Geometry Game for Handheld Devices. Accepted with modifications to Educational Technology & Society journal.

Ketamo, H. (2002d). xTask – adaptable working environment. Proceedings of WMTE 2002 - Wireless and Mobile Technologies in Education Conference, August 2002, Sweden. In press, to be released in summer 2002.

Ketamo, H. & Suominen, M. (2002). Mobile Environment for Collaboration and Work. Proceedings of IRIS'25, August 2002, Denmark. In press, to be released in summer 2002.

Ketamo, H. & Kemppinen, L. (2002). PDA's and PC's as learning platforms. Submitted to Journal of International Computer Science.

Kiili, K. (2002). Usability evaluation of digital learning environments. Proceedings of IRIS'25, August 2002, Denmark. In press, to be released in summer 2002.

Kinshuk, Oppermann, R., Rashev, R. & Simm, H. (1998). Interactive Simulation Based Tutoring System with Intelligent Assistance for Medical Education. In T. Ottmann & I. Tomek (ed.). Proceedings of ED-MEDIA / ED-TELECOM 98, p. 715-720.

Kinshuk, Oppermann, R., Patel, A. & Kashira, A. (1999). Multiple Representation Approach in Multimedia Based Intelligent Educational Systems. In S.P. Lajoie & M. Vivet (ed.). Artificial Intelligence in Education. Amsterdam: IOS Press, p. 259-266.

Kinshuk, Patel, A. & Russell, D. (2002). Intelligent and Adaptive Systems. In H.H. Adelsberger, B. Collins & J.M. Pawlowski (ed.). Handbook on Information Technologies for Education and Training. Germany: Springler-Verlag, p. 79-92.

Klausmeier, H & Allen, P.S. (1978). Cognitive development of children and youth. New York: Academic Press.

Kobsa, A., Koenemann, J. & Pohl, W. (1999). Personalized hypermedia presentation techniques for improving online customer relationships. Technical report No. 66 GMD, German National Research Center for Information Technology, St. Augustin, Germany.

Koenen, R. (1999). MPEG-4: Multimedia for our time. IEEE Spectrum, vol 36, 2/99, [http://mpeg.telecomitalialab.com/ - read 1/2002].

Lazonder, A.W. (2001). Minimalist Instruction for Learning to Search the World Wide Web. Education and Information Technologies, vol 6, 3/00, p. 161-176.

Lehtinen, E. (1997). Tietoyhteiskunnan haasteet ja mahdollisuudet oppimiselle. In: E. Lehtinen (ed.). Verkkopedagogiikka. Helsinki: Edita, p. 12-38.

Leino, J. (1997). Konstruktivismi matematiikan opetuksessa. In: Räsänen, P., Kupari, P., Ahonen, T. & Malinen, P. (ed.). Matematiikka - näkökulmia opettamiseen ja oppimiseen. Jyväskylä: Yliopistopaino, p. 39-51.

Lesgold, A. (1998). Multiple Representations and Their Implications for Learning. In M.W. van Someren, P. Reimann, H.P.A. Boshuizen & T. de Jong (ed.). Advances in Learning and Instructional Series: Learning with Multiple Representations. Oxford, UK: Elsevier Science Ltd, p. 307-319.

Li, Z. & Merrill, D. (1990). Transaction Shells: A new approach to courseware authoring. Journal of Research on Computing in Education, vol 23, p. 72-87.

Loomis, J. & Blascovich, J. (1999). Immersive virtual environment technology as a basic research tool in psychology. Behavioral Research Method, Instruments, & Computers, vol 31, 4/99, p. 557-564.

Maes, P. (1998). Agets that Reduces work and Information Overload. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 525-535.

Marttunen, M. (1997). Electronical mail as a pedagogical delivery system: An analysis of the learning of argumentation. Research in Higher Education, vol 38, 3/97, p. 345-363.

Mathieu, R.G. & Schell, G.P. (2001). An Information Scanning Approach for Learning to Work on the Internet. Education and Information Technologies, vol 6, 1/00, p. 55-61.

Maurer, H. (1996). LATE: A unified concept for a learning and teaching environment. Journal of Universal Computer Science, vol 2, [http://www.jucs.org].

Maybury, M.T. & Wahlster, W. (1998). Introduction. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 1-14.

Mayer, R.E. & Anderson, R.B. (1991). Animations need narrations: An experimental test of dual-coding hypothesis. Journal of Educational Psychology, vol 83, 4/91, p. 484-490.

Mayer, R.E. (1993). Illustrations that instruct. In: R, Glaser (ed.). Advances in Instructional Psychology. Hillsdale, USA: Lawrence Erlbaum, p. 253-284.

Mayer, R.E., Bove, W., Bryman, A., Mars, R. & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. Journal of Educational Psychology, vol 88, 1/96, p. 64-73.

Mayer, R.E. & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. Journal of Educational Psychology, vol 90, 2/98, p. 313-320.

Mayer, R.E. (2000). A redundancy effect in multimedia learning: When two modalities are worse than one. Paper presented at AERA 2000, New Orleans, USA, 24.-28.4.2000.

Mayes, J.T. & Fowler, C.J. (1999). Learning technology and usability: a framework for understanding courseware. Interacting with Computers, vol 11, p. 485–497.

McCarthy, J.E., Wayne, J.L. & Morris, J.J. (2001). Closed-Loop Adaptive Education. In Proceedings of ED-MEDIA 2001, p. 1268-1273.

McGee, S. & Howard, B. (1998). Evaluating educational multimedia in the context of use. Journal of Universal Computer Science, vol 4, [http://www.jucs.org].

Merrill, M.D., Li, Z. & Jones, M.K. (1991). Instructional transaction theory: An introduction. Educational Technology, vol 6, p. 7-12.

Mezirow, J. (1995). Fostering Critical Reflection in Adulthood : A Guide to Transformative and Emancipatory Learning. San Francisco: Jossey-Bass Publishers.

Miller, K.F. (2000). Representational Tools and Conceptual Change: The Young Scientist's Tool Kit. Journal of Applied Developmental Psychology, vol 21, 1/00, p. 21–25.

Mitsuhara, H., Kurose, Y., Ochi, Y. & Yano, Y. (2001). ITMS: Individualized Teaching Material System-Adaptive Integration of Web Pages Distributed in Some Servers. In Proceedings of ED-MEDIA 2001, p. 1333-1338.

Mullier, D.J. (1996). Integrating Neural Network Technology with Hypermedia. In Proceedings of Hypermedia at Tallinn, Estonia, [http://www.mullier.co.uk/tallinn.htm - read 1/2002].

Mullier, D.J., Hobbs, D.J. & Moore, D.J. (1998). A Web based Intelligent Tutoring System. In Proceedings NETIES, Leeds, UK, [http://www.mullier.co.uk/NETIES.htm - read 1/2002].

Mullier, D.J., Hobbs, D.J. & Moore, D.J. (1999). A Hybrid Semantic/Connectionist Approach to Adaptivity in Educational Hypermedia Systems. In Proceedings of ED-MEDIA'99, Seattle, USA, [http://www.mullier.co.uk/seattle.htm - read 1/2002].

Multisilta, J. (1996). Hypermedia Learning Environment for Mathematics. TTKK, Tampere, publications 183.

Multisilta, J. (1997a). Learning environments in the World Wide Web: xperiences from Astronomy On-Line. Education and Information Technologies, vol 2, p. 171-177.

Multisilta, J. (1997b). Miltä näyttää WWW-maailma oppimisympäristönä. In: Lehtinen (ed.). Verkkopedagogiikka. Helsinki: Edita, p. 101-111.

Multisilta, J. (2002). Mathematics and Statistics. In H.H. Adelsberger, B. Collins & J.M. Pawlowski (ed.). Handbook on Information Technologies for Education and Training. Germany: Springler-Verlag, p. 449-457.

Murray, T., Shen, T., Piemonte, J., Condit, C. & Thibedeau, J. (2000). Adaptivity in the MetaLinks Hyper-Book Authoring Framework . In Proceedings of the International Workshop on Adaptive and Intelligent Web-based Educational Systems, held in Conjunction with ITS 2000, Montreal, Canada, p. 61-71.

Murray, W.R. (1999). An Easily Implemented Linear-time Algorithm for Bayesian Student Modeling in Multi-level Trees. In Proceedings of 9th International Conference on Artificial Intelligence in Education (AI-ED 99). Amsterdam: IOS Press, p. 413-420.

Neumann, G., Krzyzaniak, S. & Lassen, C.C. (2001). The Logistics Knowledge Portal: Gateway to More Individualized Learning in Logistics. In Proceedings of ED-MEDIA 2001, p. 1400-1405.

Nielsen, J. (1999). Designing Web Usability. USA: New Riders Publishing.

Nielsen, J. & Tahir, M. (2002). Homepage Usability. USA: New Riders Publishing.

Nokelainen, P., Niemivirta, M., Tirri, H., Miettinen, M., Kurhila, J. & Silander, T. (2001). Bayesian Modeling Approach to Implement an Adaptive Questionnaire. In Proceedings of ED-MEDIA 2001, p. 1412-1413.

Norman, D.A. (1993). Things that make us smart: Defending human attributes in the age of the machine. Reading, MA: Addison-Wesley Publishing Co.

Oppermann, R. (2002). User-Interface Design. In H.H. Adelsberger, B. Collins & J.M. Pawlowski (ed.). Handbook on Information Technologies for Education and Training. Germany: Springler-Verlag, p. 233-248.

Paivio, A. (1991). Dual coding theory: Retrospect and current status. Canadian Journal of Psychology, vol 45, p. 255-287.

Papert, S. (1985). Lapset, tietokoneet, ajattelemisen taito. Jyväskylä: Gummerus. [Original book: Papert, S. (1980). Mind-storms: Children, computers, and powerful ideas. New York: Basic Books].

Papert, S. (1999). Logo Philosopy and Implementation. Logo Computer Systems Inc.

Pea, R. (1994). Seeing what we build together: Distributed multimedia learning environments for transformative communications. The Journal of the Learning Sciences, vol 3, 3/94, p. 285-299.

Penner, D.E. (2001). Cognition, Computers, And Synthetic Science: Building Knowledge and Meaning Through Modeling. In W.G. Secada (ed.). Review of Research in Education 25. Washington, DC: American Educational Research Association.

Phillips, D.C. (1995). The good, the bad, and the ugly: The many faces of constructivism. Educational Researcher, vol 24, 7/95, p. 5-12.

Phillips, D.C. (1997). How, why, what, when, and where: Perspectives on constructivism in psychology and education. Issues in Education, vol 3, 2/97, p. 151-194.

Prentzas, J., Hatzilygeroudis, I., Koutsojannis, C. & Rigou, M. (2001). Architectural Aspects of a Web-Based ITS for Teaching New Information Technologies. In Proceedings of ED-MEDIA 2001, p.1516-1521.

Raskin, J. (2000). The Humane Interface, New Directions for Designing Interactive Systems. Massachusetts: Addison-Wesley Longman Inc.

Reeves, T.C. (1996). A model of the effective dimensions of interactive learning on the World Wide Web. Paper presented at the Ed-Media 96 and Ed-Telecom 96, Boston, USA.

Reeves, T. & Laffey, J. (1999). Design, Assessment, and Evaluation of a Problem-based Learning Environment in Undergraduate Engineering. Higher Education Research & Development, vol 18, 2/99, p. 219-232.

Reeves, T.C. & Raven, A. (2002). Performance Support Systems. In H.H. Adelsberger, B. Collins & J.M. Pawlowski (ed.). Handbook on Information Technologies for Education and Training. Germany: Springler-Verlag, p. 93-112.

Resnick, L.B. (1989). Introduction. In L.B. Resnick (ed.). Knowing, learning and instruction: Essays in honor of Robert Glaser. Hillsdale, USA: Lawrence Erlbaum, p. 1-24.

Rich, E. (1998). User Modeling via Stereotypes. In M.T. Maybury & W. Wahlster (ed.). Readings in Intelligent User Interfaces. San Francisco, California: Morgan Kaufmann Publishers Inc, p. 329-341.

Riedesel, A.C., Schwarz, J.E. & Clements, D.H. (1996). Teaching elementary school mathematics. Needham heights, USA: Allyn & Bacon.

Riel, M. (2000). The Future of Technology and Education: Where are We Heading? In D.M. Watson & T. Downes (ed.). Communications and Networking in Education: Learning in a Networked Society. Massachusetts: Kluwer Academic Publishers, p. 9-24.

Ruohonen, M.J. (2001). Knowledge Networks in Information Industries - Implications to Knowledge Work Management Practices. In R. Suomi (ed.). Proceedings of t-world 2001: The 8th European Assembly on New Ways to Work, Helsinki 12-14.9.2001, p. 159-172.

Ruokamo, H. & Pohjolainen, S. (1998). Pedagogical principles for evaluation of hypermedia-based learning environments in matematics. Journal of Universal Computer Science, vol 4, [http://www.jucs.org].

Ruokamo, H. (2001). The Solver Learning Environment and Anchored Instruction on Mathematical Word Problem-Solving. In Proceedings of ED-MEDIA 2001, p. 1595-1600.

Sanchez, A., Barreiro, J.M. & Maojo, V. (2000). Design of Virtual Reality Systems for Education: A Cognitive Approach. Education and Information Technologies, vol 5, 4/00, p. 345-362.

Silfverberg, H. (1999). Peruskoulun yläasteen oppilaan geometrinen käsitetieto. Tampere: Tampereen yliopisto.

Sinko, M. & Lehtinen, E. (1998). Tulevaisuusvaliokunnan teknologiajaosto: Teknologian arviointeja 4 - Tieto- ja viestintätekniikka opetuksessa ja oppimisessa. Eduskunnan kanslian julkaisu 5/98, [WWW.eduskunta.fi – read 12/1999].

Sinko, M. & Lehtinen, E. (1999). The Challenges of ICT. Jyväskylä, Finland: Atena kustannus.

Soller, A., Cho, K-S. & Lesgold, A. (2000). Adaptive Support for Collaborative Learning on the Internet. In Proceedings of the International Workshop on Adaptive and Intelligent Web-based Educational Systems, held in Conjunction with ITS 2000, Montreal, Canada, p. 123-128.

Stanton, J. (1998). An empirical assessment of data collection using the Internet. Personnel Psychology, vol 51, Autumn 98, p. 709-716.

Tella, S., Vahtivuori, S., Vuorento, A., Wager, P. & Oksanen, U. (2001). Verkko opetuksessa - opettaja verkossa. [The Net in Teaching - The Teacher on the Net]. Helsinki: Edita.

Tilastokeskus. (2001). Tiede ja Teknologia 2000 (Science and Technology 2000). Edita: Helsinki.

Turkle, S. & Papert, S. (1990). Systems and voices within computer culture. Journal of Women in Culture and Society, vol 16, 1/90, p. 128-157.

W3C (1999). Resource Description Framework (RDF). Model and Syntax Specification. [http://WWW.w3.org/TR/1999/REC-rdf-syntax-19990222/ - read 1/2002].

W3C (2000). Extensible Markup Language (XML). 1.0 (Second Edition). [http://WWW.w3.org/TR/2000/REC-xml-20001006 - read 1/2002].

W3C (2001). XHTML™ Basic. [http://WWW.w3.org/TR/xhtml-basic/ - read 1/2002].

Valcke, M. (2002). Cognitive load: updating the theory? Learning and Instruction, vol 12, p. 147–154.

van Joolingen, W. (1999). Cognitive tools for discovery learning. International Journal of Artificial Intelligence in Education, vol 10, p. 385-397.

Webb, G.I., Pazzani, M.J. & Billsus, D. (2001). Machine Learning for User Modeling. User Modeling and User-Adapted Interaction, vol 11, p. 19-29.

Wehner, F. & Lorz, A. (2001). Developing Modular and Adaptable Courseware Using TeachML. In Proceedings of ED-MEDIA 2001, p. 2013-2018.

Whitelock, D., Romano, D., Jelfs, A. & Brna, P. (2000). Perfect presence: What does this mean for the design of virtual learning environments. Education and Information Technologies, vol 5, 4/00, p. 277-289.

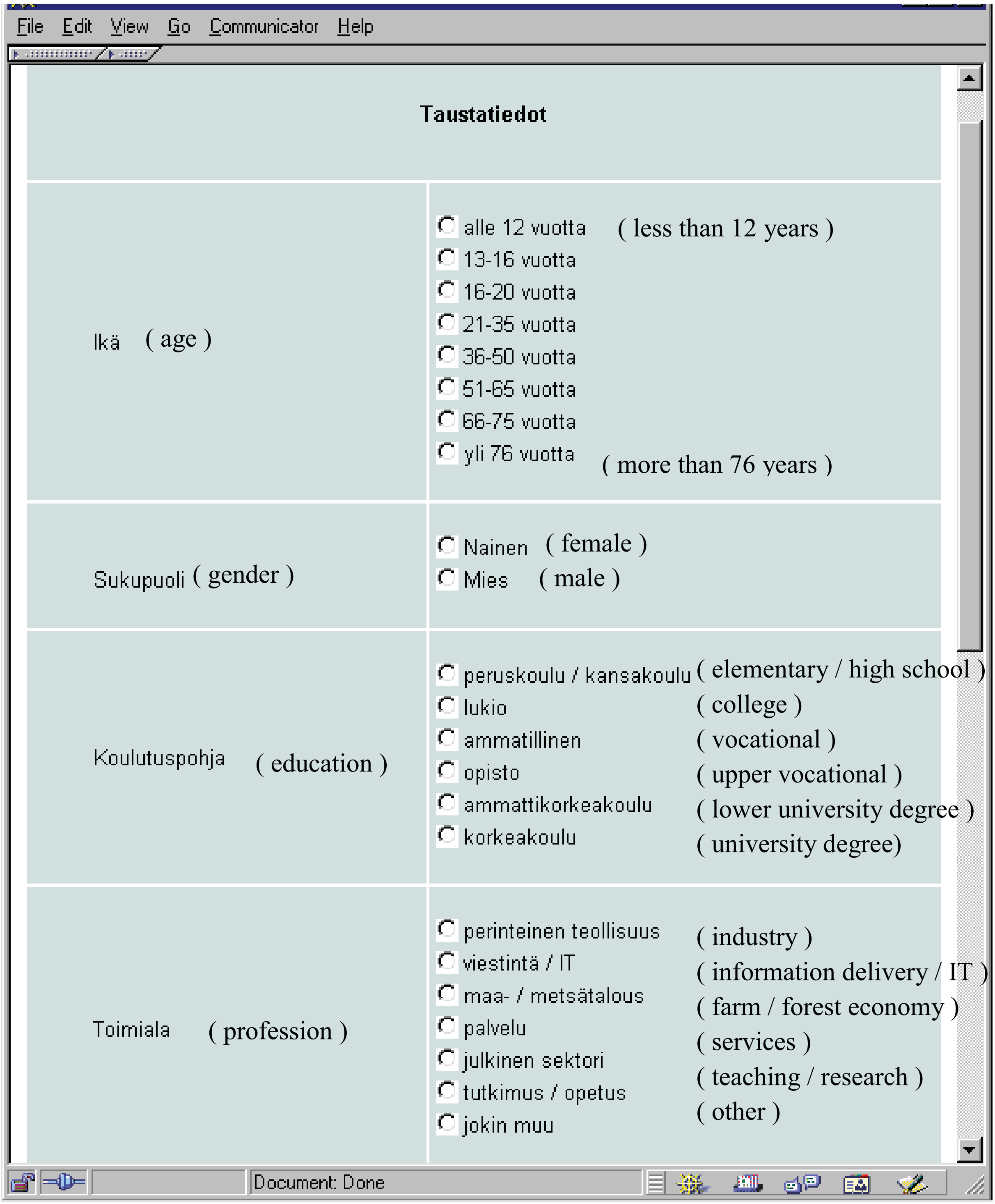
Vivet, M. (1996). The classroom as one learning environment of the future. Journal of Universal Computer Science, vol 2, [http://www.jucs.org].

List of Abbreviations

Apache	A free software web server, available: http://WWW.apache.org.
API	Application Programming Interface.
Browser	A program for presenting web content, for example Internet Explorer or Netscape Navigator.
CBT	Computer Based Training.
CGI	Common Gateway Interface. A programming interface for programs which run on a web server.
CHTML	Compact Hypertext Markup Language, a W3C specification, included in XHTML, http://www.w3.org/TR/1998/NOTE-compactHTML-19980209/
Client	A device which utilizes recourses from server.
eLearning	eLearning as a term describes that computer-based (or web-based) learning environments are used to provide training.
HTML	HyperText Markup Language, an old W3C specification, replaced by XHTML.
HTTP	HyperText Transfer Protocol
Java	A platform independent object oriented programming language, http://java.sun.com/
JavaScript	An object oriented scripting language for supporting HTML
mLearning	Mobile learning, as a term refers that mobile devices (mobile phones, PDA's and in some cases laptops with wireless network) are used to support teaching and studying.

MySql	Free software database, available: http://WWW.mysql.org
PC	Personal Computer
PDA	Personal Digital Assistant, or handheld computer. For example Compaq iPaq or Nokia Communicator
Perl	Programming language for CGI, available: http://WWW.activestate.org
RDF	Resource Description Framework, a W3C specification, http://www.w3.org/RDF/
Server	A computer that distributes resources.
W3C	World Wide Web Consortium, http://www.w3.org/
Web	World Wide Web = WWW
VRML	Virtual Reality Markup Language. Developed to describe 3D shapes in web.
WWW	World Wide Web = Web
XHTML	eXtensible Hypertext Markup Language. A reformulation of HTML 4 in XML 1.0, a W3C specification, http://www.w3.org/TR/xhtml1/
XHTML Basic	eXtensible Hypertext Markup Language Basic, a simplified set of XHTML especially for mobile devices, reader devices and TV's, a W3C specification, http://www.w3.org/TR/xhtml-basic/
XML	eXtensible Markup Language, a W3C specification, http://www.w3.org/XML/

Appendix A – The questionnaire for the readability study

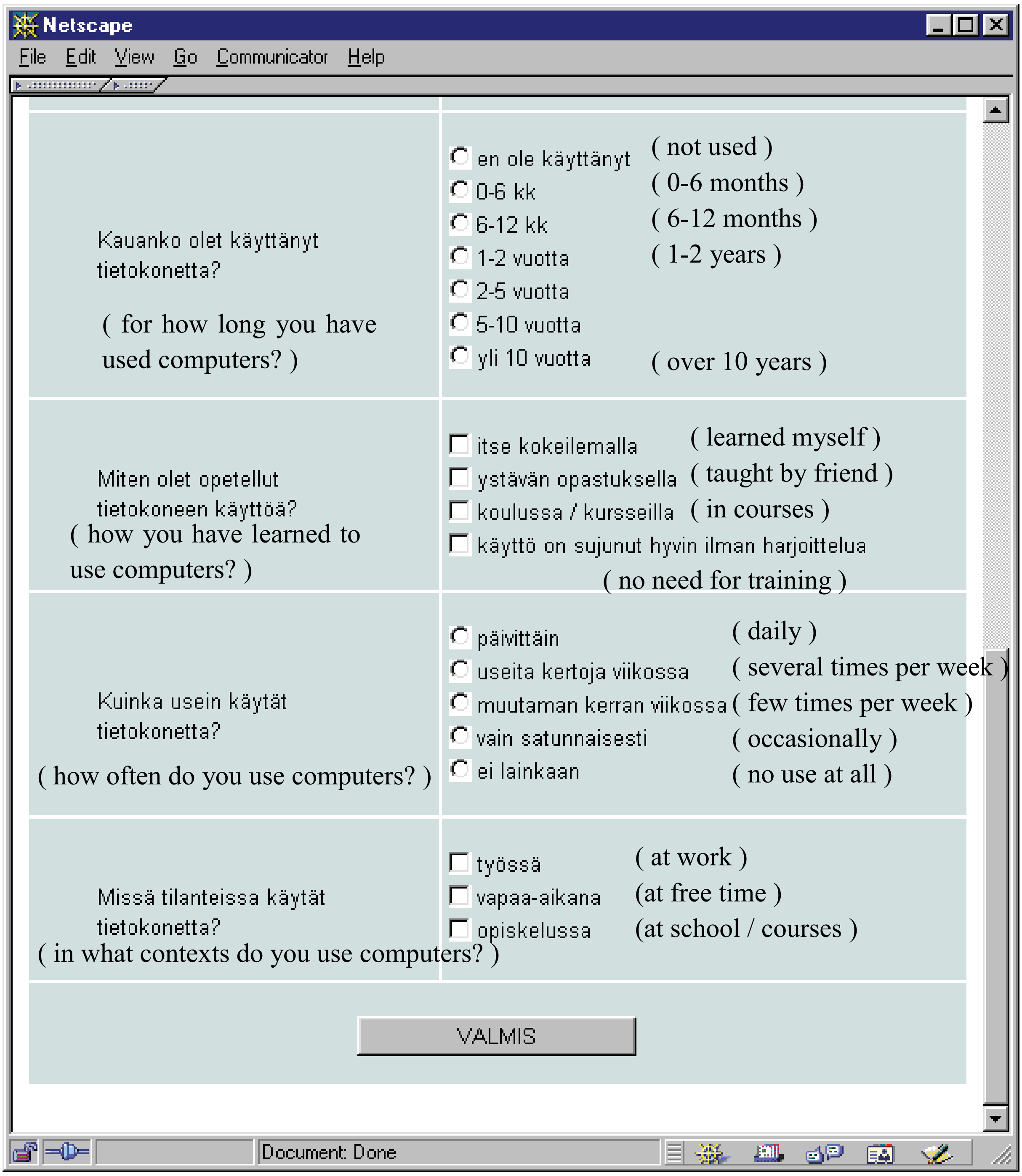


File Edit View Go Communicator Help

Taustatiedot

Ikä (age)	alle 12 vuotta (less than 12 years) 13-16 vuotta 16-20 vuotta 21-35 vuotta 36-50 vuotta 51-65 vuotta 66-75 vuotta yli 76 vuotta (more than 76 years)
Sukupuoli (gender)	Nainen (female) Mies (male)
Koulutuspohja (education)	peruskoulu / kansakoulu (elementary / high school) lukio (college) ammatillinen (vocational) opisto (upper vocational) ammattikorkeakoulu (lower university degree) korkeakoulu (university degree)
Toimiala (profession)	perinteinen teollisuus (industry) viestintä / IT (information delivery / IT) maa- / metsätalous (farm / forest economy) palvelu (services) julkinen sektori (teaching / research) tutkimus / opetus jokin muu (other)

Document: Done



Netscape

File Edit View Go Communicator Help

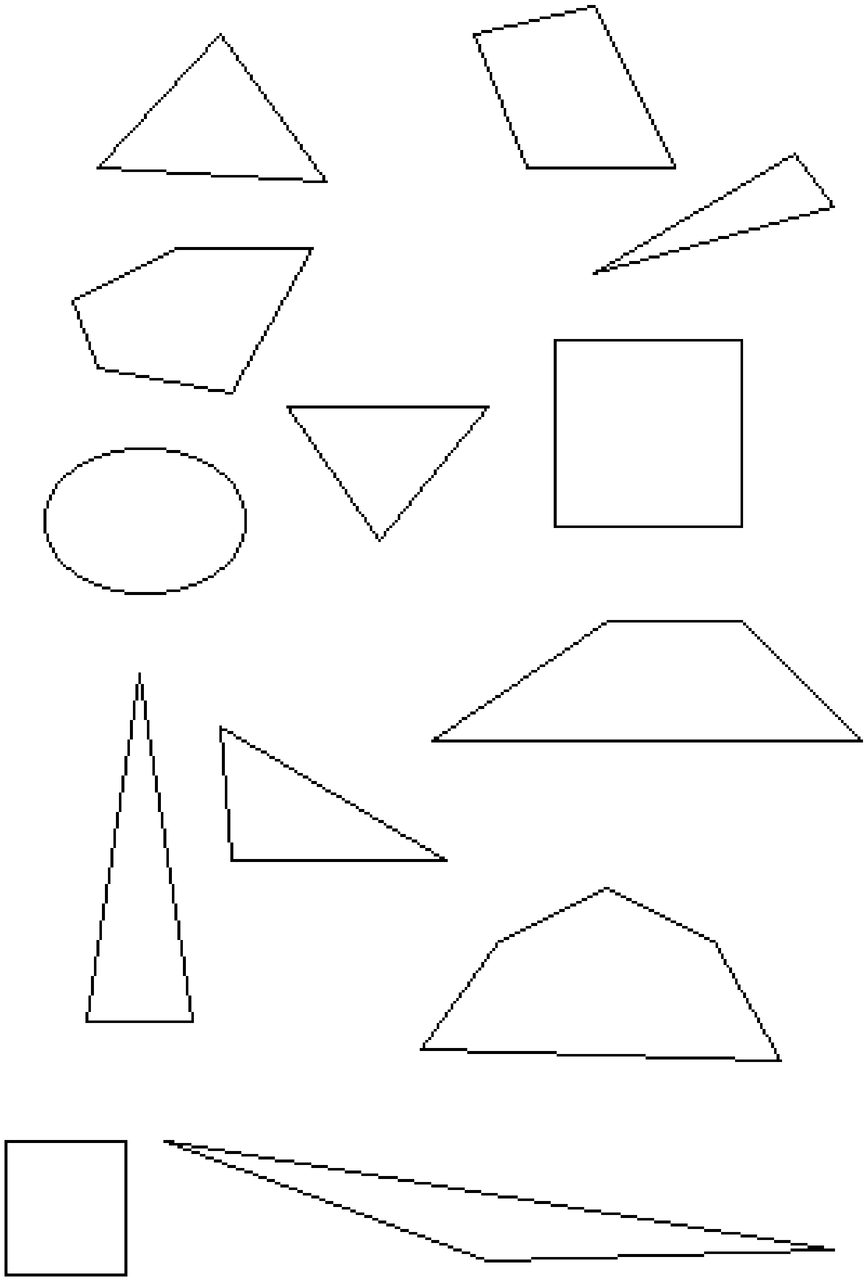
Kauanko olet käyttänyt tietokonetta? (for how long you have used computers?)	en ole käyttänyt (not used) 0-6 kk (0-6 months) 6-12 kk (6-12 months) 1-2 vuotta (1-2 years) 2-5 vuotta 5-10 vuotta yli 10 vuotta (over 10 years)
Miten olet opetellut tietokoneen käyttöä? (how you have learned to use computers?)	itse kokeilemalla (learned myself) ystävän opastuksella (taught by friend) koulussa / kursseilla (in courses) käyttö on sujunut hyvin ilman harjoittelua (no need for training)
Kuinka usein käytät tietokonetta? (how often do you use computers?)	päivittäin (daily) useita kertoja viikossa (several times per week) muutaman kerran viikossa (few times per week) vain satunnaisesti (occasionally) ei lainkaan (no use at all)
Missä tilanteissa käytät tietokonetta? (in what contexts do you use computers?)	työssä (at work) vapaa-aikana (at free time) opiskelussa (at school / courses)

VALMIS

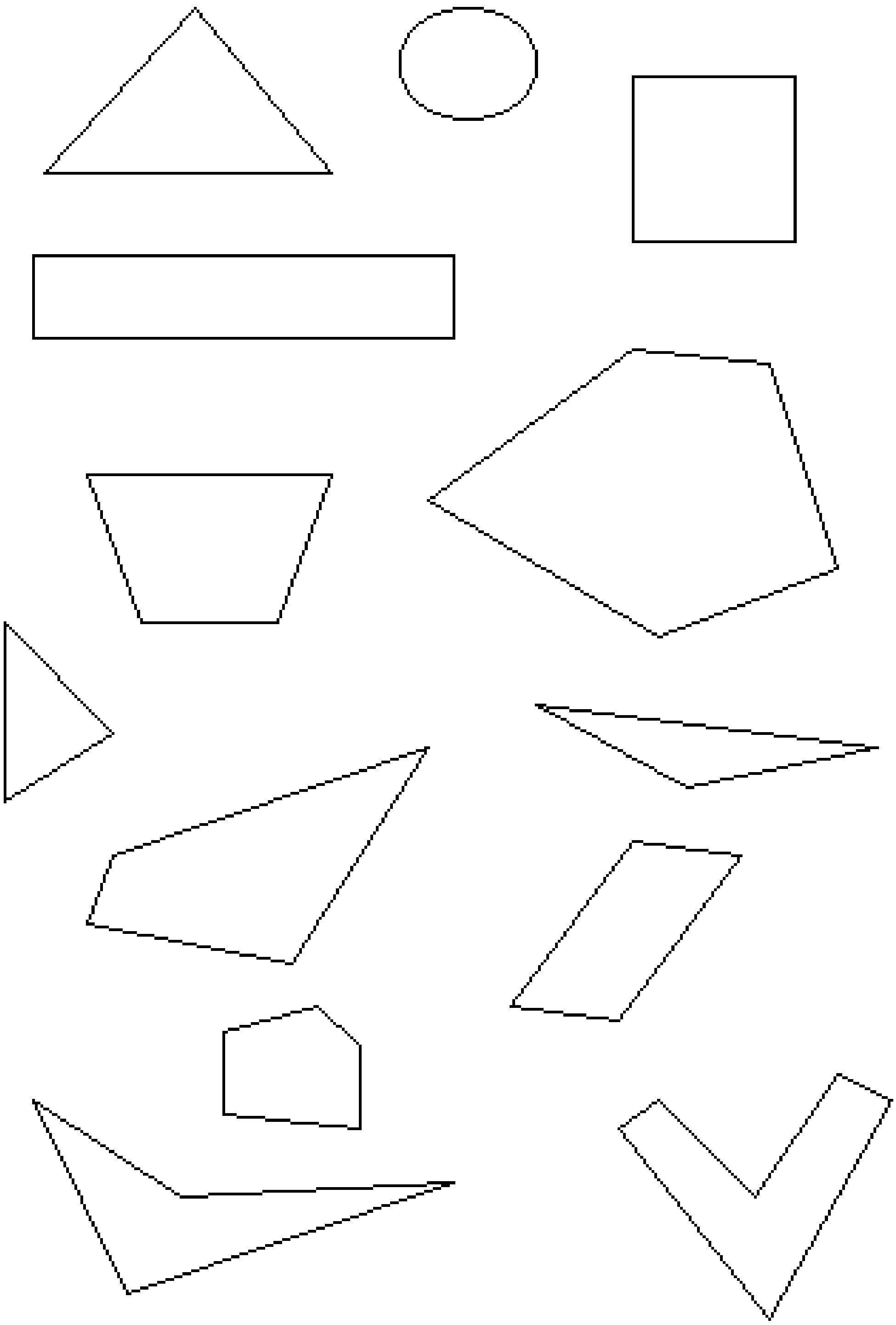
Document: Done

Appendix B – The pre- and post test of the geometry study

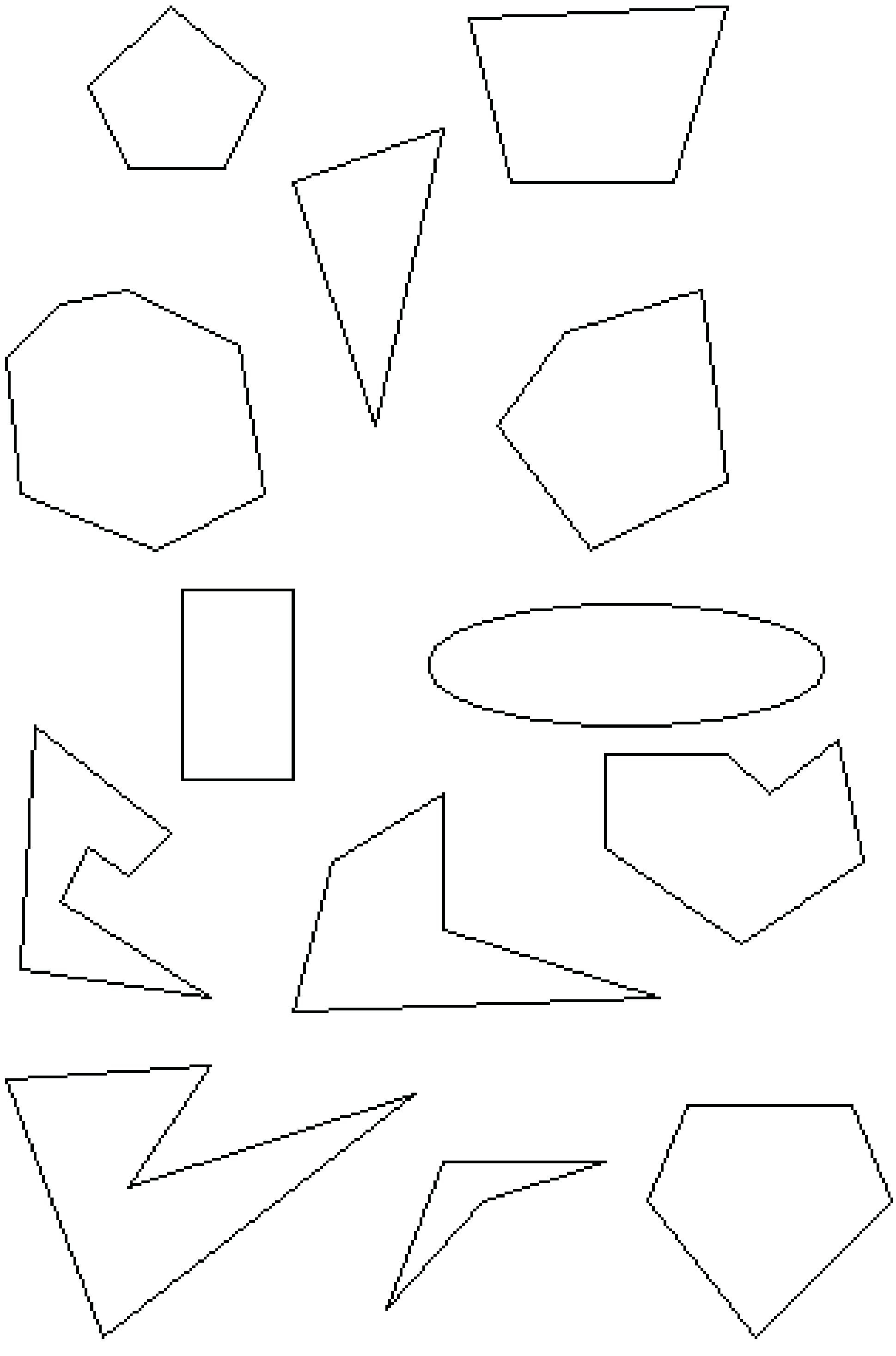
Ympäröikolmiot



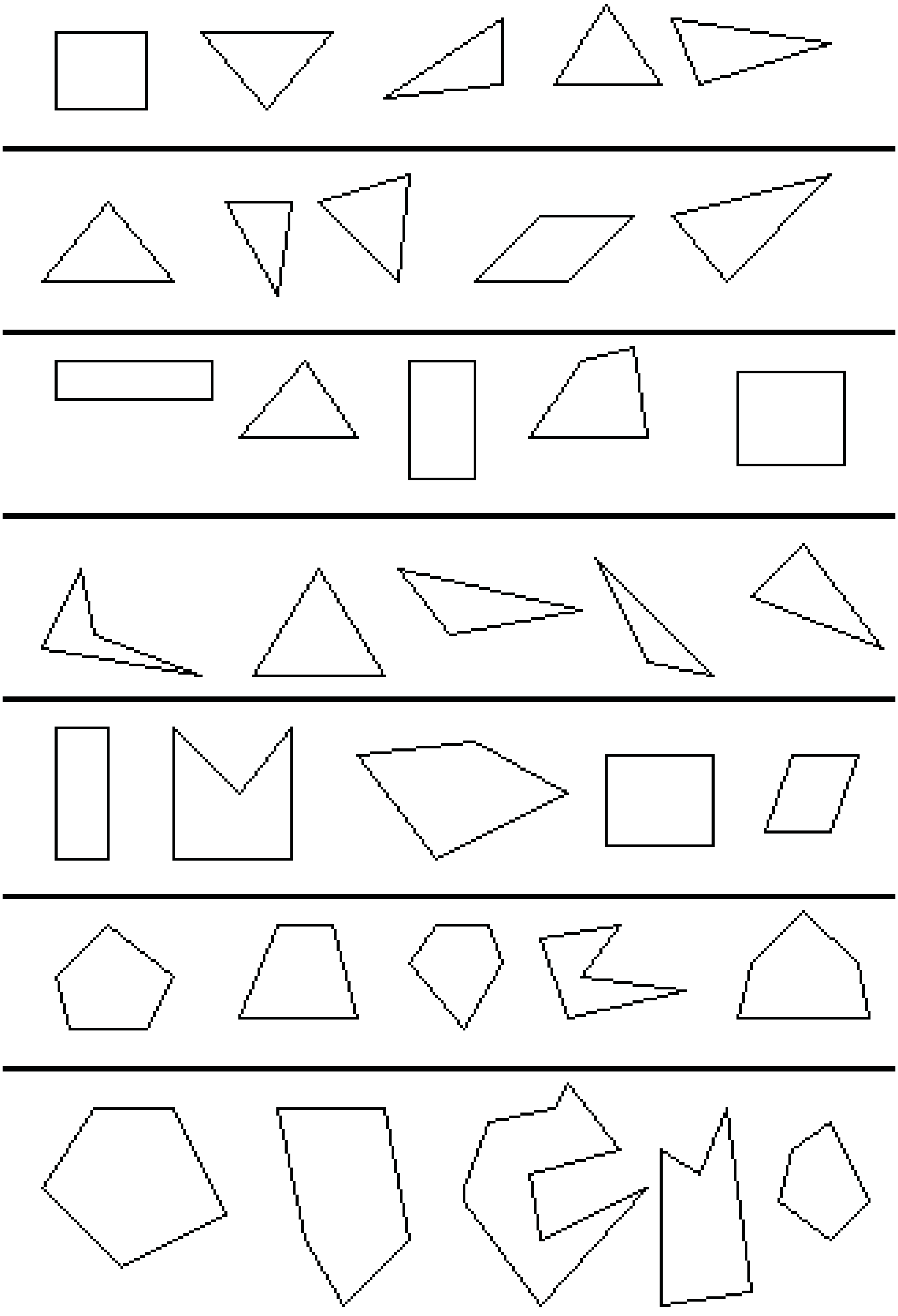
Ympäröi nelikulmiot



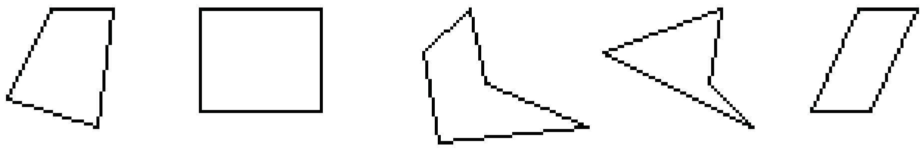
Ympäröi viisikulmiot

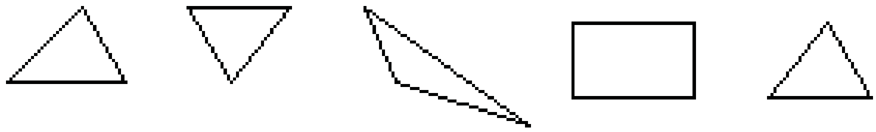


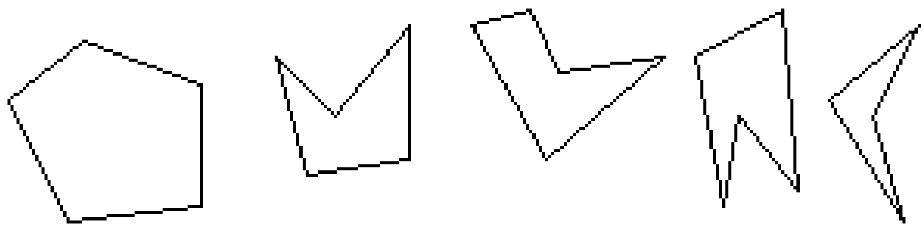
Mikä ei kuulu joukkoon?

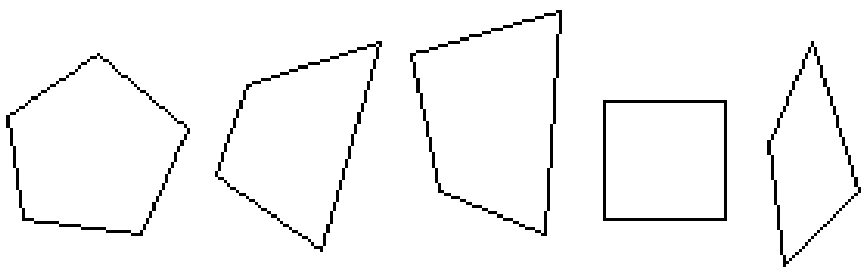


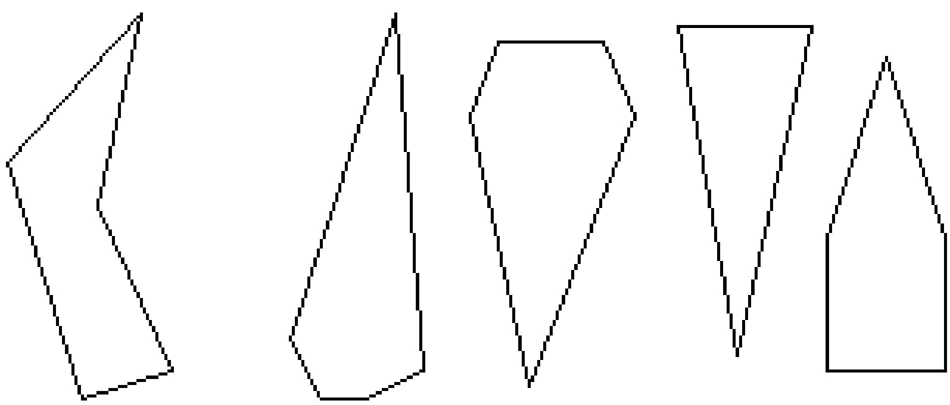
Mikä ei kuulu joukkoon?











Piirrä neljä erilaista kolmiota

Piirrä neljä erilaista nelikulmiota

Piirrä neljä erilaista viisikulmiota

Tampereen teknillinen korkeakoulu
PL 527
33101 Tampere

Tampere University of Technology
P. O. B. 527
FIN-33101 Tampere Finland