

DISSERTATIONES PEDAGOGICAE SCIENTIARUM
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**PROBLEM SOLVING
IN WEB-BASED
LEARNING ENVIRONMENT**

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, which will be referred to in the text by their Roman numerals:

- I **Pedaste, M., & Sarapuu, T.** (in press). The factors influencing the outcome of solving story-problems in a Web-based learning environment. *Interactive Learning Environments*. (accepted 2 May 2006)
- II **Pedaste, M., & Sarapuu, T.** (2006). Developing an effective support system for inquiry learning in a Web-based environment. *Journal of Computer Assisted Learning*, 22, 42–67.
- III **Pedaste, M., & Sarapuu, T.** (2005). Developing students skills to analyse data in web-based inquiry learning environment ‘Hiking Across Estonia’. In V. Uskov (Ed.) *Proceedings of the 8th IASTED International Conference on Computers and Advanced Technology in Education (CATE)* (pp. 353–358). Calgary: ACTA Press.
- IV **Pedaste, M., & Sarapuu, T.** (2005). The effectiveness of problem solving strategies used in web-based inquiry learning. In M. Ergazaki, J. Lewis, & V. Zogza (Eds.) *Trends in Biology Education Research in the New Biology Era* (pp. 243–256). Patras: Patras University Press.
- V **Pedaste, M., & Sarapuu, T.** (2004). Acquiring scientific inquiry skills in exploratory learning environment. In A. Laine, J. Lavonen, & V. Meisalo (Eds.) *Current Research on Mathematics and Science Education. Proceedings of the XXI Annual Symposium of the Finnish Association of Mathematics and Science Education Research* (pp. 591–611). Helsinki: University of Helsinki.
- VI **Pedaste, M., & Sarapuu, T.** (2004). Developing students’ problem solving skills by learning simulation ‘Hiking Across Estonia’. In C. P. Constantinou, & Z. C. Zacharia (Eds.) *Computer Based Learning in Science. Conference Proceedings 2003. Volume II — The Educational Potential of New Technologies* (pp. 218–228). Nicosia: University of Cyprus.
- VII **Sarapuu, T., & Pedaste, M.** (2001). A pilot study of the Web-based environmental simulation. In J. Price, D. A. Willis, N. Davis, & J. Willis (Eds.) *Proceedings of SITE2001 — March 5–10, 2001 Orlando, Florida. Association for the Advancement of Computing in Education* (pp. 2558–2562). Norfolk: AACE.

1. INTRODUCTION

The main goal of the present research has been designing a web-based learning environment that enables to develop students' skills to solve story problems effectively when learning in small groups without any guidance by a teacher. The study can be divided into three stages: developing the learning environment and evaluating its effectiveness; differentiating and characterising the learners' groups in order to design appropriate support system for them; evaluating the support system and providing a final list of factors that have statistically significant influence on learning to solve story problems in web-based environments.

The current work started with composing a situational learning simulation 'Hiking Across Estonia' (<http://bio.edu.ee/matk/>). This type of environment is appropriate for our research since it provides students with an opportunity to virtually explore processes and phenomena of the world, manipulate variables, observe the effects of their operations, and make experiments to discover relations between variables (Alessi & Trollip, 1985). Many researchers have also demonstrated that computer simulations have a positive effect on the development of learners' problem solving skills (Shute & Glaser, 1990; de Jong & van Joolingen, 1998; Kuhn et al., 2000; Abrams et al., 2001; Reid et al., 2003).

The learning environment 'Hiking Across Estonia' contained initially 35 story problems of ecology and environmental education. The problems were presented in a pre-defined sequence according to their type and content and the environment made it possible to rearrange them. Story problems are defined as the problems where the information is situated into a context that is presented in text-based and visual forms (see Zweng, 1979; Sherrill, 1983). In our studies, students solved problems in small groups consisting of three to five learners in a situated virtual hike through five ecosystems: heath forest, grove, meadow, waterside meadow, and bog. In addition, the learning environment provided learners with virtual equipment for making some experiments and informative pages with all the facts needed for solving problems. Students were also given the opportunity to get prompts before solving particular problems and feedback after solving them. The first research question is related to the evaluation of this simulation: What is the effectiveness of the web-based learning environment 'Hiking Across Estonia' in developing problem solving skills in small groups of students from the 6th to 12th form?

The results of the first stage of the research revealed that more than a half of these learners' groups did not improve statistically significantly in the performance of solving story problems without any additional support. This finding corresponds with a number of studies, which have indicated that problem solving in computer-based programmes is more effective when students are provided with appropriate guidance and support (de Jong et al.,

1999; Reid et al., 2003; Quintana et al., 2004). Designing an effective support system for acquiring problem solving skills in small groups of learners in a web-based environment was also one aim of this research. However, many studies have demonstrated that support, which is adapted according to the learners' characteristics, is significantly more effective than pre-defined general support that is provided in the same way to all learners (see Reid et al., 2003). The support system can be designed on the basis of internal factors describing the learners' groups and external factors deriving from the characteristics of problems and learning environment (Funke and Frensch, 1995). Since it is essential to differentiate the types of learners' groups on the basis of their characteristics the second research question is: What types of students' groups can be differentiated in solving story problems in a web-based learning environment and what are the characteristics of these types?

Next, the types of learners' groups were found by cluster analysis on the basis of groups' general characteristics and performance in problem solving. The latter involved their results in the pre- and post-tests and virtual hike. In order to characterise the types of these groups, four internal factors were selected: the size of the group, the ratio of genders, the age of the members, and the initial level of problem solving skills. The importance of group size and members' age on the effectiveness of problem solving is demonstrated in the work of Cohen (1994) and the role of gender is derived from the study of Strough et al. (1996). The level of problem solving skills in computer-based environments also depends on students' metacognition and situation awareness (Kentrige & Heywood, 2000; Sonnenwald, 2004). Thus, the third research question is: What are the characteristics of a support system needed for different types of learners' groups in order to increase their effectiveness in acquiring skills to solve story problems?

The support system of the learning environment 'Hiking Across Estonia' was designed on the basis of the most important differences between the types of learners' groups. This system consisted of rearranging the problem tasks and adding supportive notes. The significant influence of the sequence of tasks on the learning outcome in the context of mathematics and languages has been already proved by Landa (1974, 1976). Some types of learners' groups needed the initial sequence of the problem solving tasks in 'Hiking Across Estonia' to be rearranged. The supportive notes have been designed to promote particular types of groups' situation awareness in particular to increase their metacognition (Kentrige & Heywood, 2000; Sonnenwald, 2004).

Following the study on the characteristics of learners' groups and support system, the fourth research question has arisen: Which internal and external factors have statistically significant influence on the effectiveness of learning to solve story problems cooperatively in a web-based environment? A list of factors that have a significant influence on groups' performance in acquiring problem solving skills has been compiled on the basis of the research.

2. REVIEW OF LITERATURE

The aim of the current research has been designing a web-based learning environment for developing students' problem solving and inquiry skills when they learn in small groups without the guidance of a teacher. Therefore, the section of literature gives an overview of different types of problems and problem solving, inquiry learning in relation with the concept problem solving, and some aspects concerning web-based learning environments developed for solving problems collaboratively.

2.1. Problem solving and inquiry learning

2.1.1. What is a problem?

Jonassen (2000) defines a problem as the existence of an unknown entity for which the problem solver has to find a value. The unknown entity in a situation is elaborated through the difference between a current state and goal state. In the current state we have a problem and in the goal state we have a solution for that. According to the second aspect — the social, cultural, or intellectual value — a problem is not a real problem if the problem solver does not believe that it is worth finding the unknown entity. Robertson (2001) uses a concept initial state as a synonym for the current state and also adds an important aspect to the definition of a problem. He points out that a main attribute of a problem is that it is not exactly known how to reach the goal state. Arlin (1989) also describes expressively that problems are real problems only when there is a 'felt need' that motivates people into searching for a solution in order to eliminate discrepancies between the initial and goal state. All these aspects — difference between initial and goal state, value for solving, and some uncertainty in the solution strategy — are presented in the definition of Nitko (2001). According to Nitko (2001, p. 210) 'a student incurs a problem when the student wants to reach a specific outcome or goal but does not automatically recognize the proper path or solution to use to reach it'.

The problems are traditionally described using four characteristics (Jonassen, 1997): i) problem domain, ii) problem type, iii) problem solving process, and iv) solution. The problems provided for the students of our research originate from school biology, especially from the different topics of ecology and environmental education. However, our research is not primarily domain-specific, although it remains a significant factor influencing the process of problem solving. The fourth characteristic — the type of solution (convergent or divergent) — is later used for the typology of problems (see Jonassen, 2000) and, therefore, we only concentrate our discussion on the problem types and problem solving process.

The development of problems' typology starts with the work of Newell and Simon (1972) and is closely related to the level of problem difficulty. Newell and Simon divided all problems into simple and complex (Newell & Simon, 1972). Simple problems usually have one correct answer and there is an often already formerly applied algorithm for solving the problem whereas complex problems have many answers almost at the same level of correctness and there are different strategies for solving these problems. Generally, a complex problem contains a number of simple ones.

Simon (1973) adds the distinction between well- and ill-structured problems. If the typology of simple and complex problems mainly takes into account the strategy and result of the problem solving then the distinction between well- and ill-structured problems sheds some light on the problem itself. A well-structured problem has a structure, which is recognizable by the learner and some formerly used steps can be applicable for solving it. An ill-structured problem is really new for the problem solver and a new strategy for solving it has to be developed. Jonassen (1997) referees the ideas of Wood (1983), Spiro et al. (1987, 1988), and Meacham and Emont (1989) and lists the following characteristics of well- and ill-structured problems.

A well-structured problem:

- It has all elements of the problem presented in the problem description;
- There is one probable solution;
- It engages the application of a limited number of rules and principles;
- It involves concepts and rules that are regular and well-structured in a particular domain of knowledge;
- There is one answer that is more correct than others;
- It has comprehensible solutions where the relationship between choices and all problem states are known or probabilistic;
- It can be solved according to a preferred prescribed strategy.

The characteristics of an ill-structured problem are the following:

- There are more unknown elements of the problem;
- It engages multiple strategies for solving it and for evaluating solutions;
- The element of uncertainty is present concerning the concepts, rules, and principles that have to be applied in solving that problem;
- There are inconsistent relationships between concepts, rules, and principles in various cases;
- There are not prototypic cases due to the context and/or level of the importance of the parameters involved in the problem;
- There are no general rules for describing or predicting most of the cases;
- There are no explicit means for determining appropriate action;
- Learners have to express personal beliefs about the problem and, therefore, problem solving is uniquely human interpersonal activity;
- Learners have to make decisions about alternatives and to defend their choices.

The terms of well- and ill-defined problems are generally less-used synonyms for well- and ill-structured problems. However, a very clear distinction between ill- and well-defined problems is proposed by Robertson (2001). He has described four characteristics of problems: i) initial state, ii) goal state, iii) operators, and iv) restrictions. If all these four are presented in a problem statement then it is well-defined whereas in the case of ill-defined problems, at least one of them is unknown. However, all these dual categorisations are dealing with the same variables and do not add distinct value for describing the process of solving problems in a deeper manner of wide area of real situations.

While looking for general categorisation of problems Robertson (2001) gives some examples as to what has to be taken into account: i) prior knowledge required to solve a problem, ii) the nature of the goal involved, iii) the complexity of the problem, iv) whether the problem tells us everything that is needed to know to solve it, or whether a problem solver has to work out a strategy to be implemented, v) whether it is the same as the one the problem solver has solved before, vi) whether it is a complex problem or can be solved in one step if a problem solver only knows what that step is. However, Robertson only introduces the possibility of making a typology of problems and does not propose a complete classification. Therefore, we have to look into the typology of problems proposed by Jonassen (2000). He collected hundreds of different problems and described them using cognitive task analysis. As a result, 11 types of problems were distinguished. However, he also used the dimension of well- and ill-structuredness. Starting from the simple well-structured problems and moving on to the most complex ill-structured ones, these types are: i) logical, ii) algorithmic, iii) story, and iv) rule-using problems with one most correct answer, and v) decision-making, vi) troubleshooting, vii) diagnosis-solution problems, viii) strategic performances, ix) case analysis problems, x) design problems, and xi) dilemmas with multiple answers at almost the same level of correctness.

In solving logical problems, students have to apply logical control and manipulation of limited variables (Jonassen, 2000). Generally, it is the only type of problem in which there is minimal need for domain knowledge. The level of success in solving logical problems can be measured by time the students spent on solving or the number of manipulations made in reaching the goal state. However, there might be a different specific method for solving each logical problem that is not transferable from one learning situation to another (Reed et al., 1974; Hayes & Simon, 1977). For example, if you know how to complete a puzzle then you have no advantages in solving a problem like Rubic's Cube and vice versa (Jonassen, 2000).

The key element of algorithmic problems is a formula or procedure that has to be applied correctly in order to solve a particular problem. Learner has to identify a correct strategy or formula and all after that is only simple calculation (McCloskey et al., 1985). It is also argued that algorithmic problems are not real problems because they presume only the knowledge about certain steps that

have to be carried out in finding the solution (Smith, 1991). According to the subtler view, these tasks will be problems if learners are required to modify an algorithm before using it (Jonassen, 2000). Jonassen also argues that the similarity of 'real problems' increases with the complexity of the tasks. For example, no one doubts that finding a pattern in a set of data is a problem, although it reveals in applying different algorithms.

Story problems, also called word problems can be regarded as the most common type of problem at schools (Jonassen, 2003). Therefore, it is understandable that many studies on the design theory and characteristics of these problems have been carried out (see Zweng, 1979; Sherrill, 1983; Hegarty et al., 1995; Lucangeli et al., 1998; Jonassen, 2000; Jonassen, 2003; Jonassen, 2004). Story problems are those where information is situated in some kind of context (Jonassen, 2000). Therefore, this type is much more similar to every-day life problems compared with algorithmic ones. The story is a description of a situation containing both textual and visual information. First, learners are required to analyse the information and select the key concepts of the problem (Sherrill, 1983). Next, they have to select the algorithm or develop the strategy based on many different algorithms and apply it paying attention to evaluating their solutions.

The rule-using problems are comparable with algorithmic problems. In both cases learners have to find an algorithm for solving the task (Jonassen, 2000). However, there is a big number of different pathways in the case of rule-using problems and the main activity in problem solving is to find the best algorithm not only to apply a correct one. In both cases, the goal is very clear and key interest stays on the strategy. For example, playing chess is a complex rule-using problem. Although there are very simple rules for moving pieces on the board in chess, it is still very difficult to win the game against an experienced player.

The indicator for decision-making problems is selecting an answer to the question from a set of alternatives that have one or more consequences (Jonassen, 2000). This type is more complex than the four types described above as it includes analysing the advantages and disadvantages of different solutions. There is no correct answer from every viewpoint or for any problem solver and, often the decision-making in real situations is not a rational process (Mullen & Roth, 1991).

Troubleshooting problems take into consideration the multiple pathways that are available for solving the problems while the goal is very clear (Jonassen, 2000). However, apart from rule-using problems there are no simple rules for solving the problem and these pathways have to be developed generally by experimentation.

Diagnosis-solution problems are similar to troubleshooting but the situation is more complex and there is a big number of optional solutions (Jonassen, 2000). The problem solver has to find the appropriate pathway for each particular case in accordance with the previous actions concerning analogous

cases. For example, achieving any kind of medical diagnosis and treatment represents that type of problem.

The next type of problem, strategic performances are similar to troubleshooting but in this case the situation is changing in time and, therefore, the problem solver has to maintain a relevant situational awareness in order to solve this problem (Jonassen, 2000). It means that the problem solver has to take into account all conditions of the problem at the exact time and in some seconds the conditions may change and also the best solution has to be changed.

Case-analysis problems are even more complex compared with strategic performances while not only the changes in real time but also the decisions made in the past have to be taken into account (Jonassen, 2000). In addition, the goal is vaguely defined. However, Williams (1992) argues that these problems emerge from instruction not from real life. Examples of these are analysis of cases, preparing briefs, and defending judgements that are all authentic activities for law and medical students.

One very complex type of problem as regarded by Jonassen (2000) is design problems. These have ambiguous specification of goals, no determined solution path, and the need to integrate multiple knowledge domains (Reitman, 1965; Simon, 1973). Often, there is an unknown number of degrees in freedom in the case of design problems and there are no possibilities for dividing the solutions into correct and wrong ones while these are only better or worse for some conditions or for some people (Goel & Piroli, 1989).

The eleventh type of problem is dilemma, which is the most ill-structured type because the best solution is not the best for anyone (Jonassen, 2000). In this case, a problem solver has to analyse all personal, social, ethical, or scientific aspects concerning that problem and to find a compromise that is acceptable for most of the interest groups involved in this dilemma. This solution is also called the 'common good' that is really not the best for no one (Schroeder, 1995).

In the current research, we were interested in story problems of biology that were presented in a situated context. The presentation of situations of particular problems was presented with different types of information that had to be analysed: texts, graphs, photos, tables, and figures. All the problems were completely new for students. They had to develop a strategy for solving the problem that means students had to reach from the initial problem state to the goal state.

While the story problems are presented as situations these also relate to the theory of situated learning proposed by Lave (1988). In the theory of situated learning, Lave (1988) proposes two important principles: i) knowledge has to be presented in an authentic context, ii) learning requires social interaction and collaboration. According to this, learning is mainly happening in meaningful context and culture and the activities of socially interacted learners have to be situated into this context. Solving that kind of problem enables students to acquire skills first and foremost for their everyday needs while each new

situation in real life differs from the previous one and, therefore, what would solve the problem in one situation does not solve it in another case (Doornekamp, 2001).

In the present research, a situational learning simulation ‘Hiking Across Estonia’ has been developed in order to provide learners with authentic environment for a virtual trip where they are faced with various problems that have to be solved by collaborative groups.

2.1.2. How to solve problems?

According to a general definition, problem solving is any goal-directed sequence of cognitive operations (Anderson, 1980). Jonassen (2000) adds that this process starts with constructing a mental representation of the problem situation that will be the frame for all the following activities. A mental representation of a problem is mainly an internal process. Therefore, it is not easy to evaluate how a learner understands problems. However, the learner can make an external representation of problem solving that is applicable for evaluating problem solving skills. It means that we have to make a presumption that external representations are the reflections of the internal mental model (see Smith, 2003). On the other hand, in addition to problem solving skills, we have to pay some attention to knowledge. According to the view of Taconis and co-workers (2001) it is possible to make a clear distinction between knowledge base (domain and general knowledge) and skills base (the ability to perform). Dual-code theory (McNamara, 1994, 1999) even claims that knowledge and skills base can be mentally encoded in different ways and are acquired in relatively independent processes. Thus, this chapter is divided into three parts: i) strategy for problem solving, ii) problem solving skills, and iii) knowledge needed for problem solving.

Many researchers have tried to work out a general strategy for problem solving almost during a century, starting with Dewey’s (1910) work. Dewey applied the steps of scientific method for describing the process of solving problems and proposed four stages: i) identification of the problem, ii) proposing solutions, iii) argumentation of solutions, iv) controlling and proving these. Principally different approach has been developed by Wallas (1926). He found that personal experience of analogical cases has a stronger influence on problem solving, rather than general strategy of scientific method. However, all different descriptions of the process worked out during the next decades are similar to these two (see Polya, 1945, 1962; Johnson, 1955; Kingsley & Garry, 1957; Osborn, 1953; Parnes, 1967; Newell & Simon, 1972; Rubinstein, 1975; Simon, 1978; Bransford & Stein, 1984; Stepien et al., 1993; Etter, 1995; Meier et al., 1996; Hartman, 1996). Perhaps the most widely used is the theory of IDEAL problem solver developed by Bransford & Stein (1984). They proposed

five stages: i) identification of problem, ii) defining and representing it, iii) exploring possible strategies for problem solving, iv) acting on those strategies, and v) looking back and evaluating the effects of all activities. However, all these theories are applicable only for common purposes and fail when used for instruction since they are too general and do not take into account a large variety of problem types. Yet, Sweller (1988) has found out that generalised problem solving strategies are only important for novices while the experts recognise each problem situation as belonging to a certain class of problems and apply a specific strategy for solving it. Therefore, it can be concluded that the strategy of problem solving depends on the type of particular problem and the general strategy cannot be applied for solving all eleven types of problems introduced above.

Robertson (2001) differentiates ‘strong methods’ and ‘weak methods’ among problem solving. The first ones are domain-specific and learnable and they are applicable when the learner already knows how to solve the problem. On the other hand, ‘weak methods’ are those applied for solving the more complex and ill-structured problems. These are general-purpose problem solving strategies that can not be implemented directly whereas these have to be modified by the problem solvers.

Jonassen and Land (Jonassen, 1997; Jonassen & Land, 2000) look for general strategies separately for well- and ill-structured problems. They suggest that the process of solving well-structured problems is usually related to information-processing theories, while ill-structured problems share assumptions with constructivism and situated cognition. The learning outcomes for the first theory are especially generalised skills that can be applied across content domains whereas constructivism and situated cognition assume the domain specificity. However, the dichotomy approach of problem solving strategies is still too general and, therefore, in this thesis we concentrate on the process of solving ill-structured story problems and give a deeper overview of the solving strategies for this type of problem.

Rich (1960) proposes the following procedure for solving story problems: i) representation of the unknown by letters, ii) translation of relationships about unknowns into equations, iii) solution of equations to find the value of three unknowns, iv) verification or check of values found, to see if they fit the original problem. All learners at school are familiar with similar ‘direct translation strategy’ for solving drill and practice tasks and sometimes this ‘learning’ is so automated that they do not think at all on the situation of the problem. Still, students fail in a little more complicated case due to hanging on to the numbers and key words that they select from the problem (Hegarty et al., 1995). This approach can end with misunderstanding the nature on making science. However, in biology, the story problems are more complex and ill-structured and, therefore, this simple guide is not applicable and we have to introduce more sophisticated ones.

Sherrill (1983) describes four stages in solving story problems: i) identifying key words in the story, ii) selecting appropriate algorithm and sequence for solving the problem, iii) applying the algorithm, and iv) evaluating the results. The important difference of this strategy compared with Rich (1960) is that it does not focus on numbers. It enables students to pay more attention to the situation in the story. Nevertheless, the most critical stage in this list is the first one, where learners often attend to unimportant phrases of the story or focus too closely on surface features of the problem and, therefore, fail in selecting the correct algorithm or transferring previously used solutions into the new context or features (see Sherrill, 1983; Novick, 1988; Blessing & Ross, 1996; Woods et al., 1997). For example, Prawat (1989) described how students of the second form solved the following simple story problem: 'there were 26 lambs and 10 goats in a ship. What is the age of the captain?' It appeared that 75 % of the students said that the correct answer is 36. It demonstrates convincingly that often learners do not analyse all the conditions presented whereas they tend to think only about numbers or symbols in the story and forget the situation. It means that students try to use analogies in problem solving but fail in that. According to Reed (1992), using analogical problems requires recognition of the similarity between the current and previous problems and the ability to recall the solution method used previously. Learners can make mistakes either in the first or second step. However, the fourth stage — evaluating the results — is needed for avoiding that kind of faults but many students do not pay any attention to evaluation and, therefore, propose the first result found in application an algorithm as the final one. We can conclude that the process of analysing both verbal and visual information in a story problem and the evaluation of all activities are the most crucial factors that have an influence on the learning outcome.

For overcoming the problems derived from the absence of connections between key words and numbers, problem situation and solutions, evaluation of each step in the solving process, Hayes and Simon (1976) have proposed that successful problem solvers have better conceptual models of problems. These are mental representations of the pattern of information that is presented in the story, also called problem schemas (Riley & Greeno, 1988). The definition of schemata varies a little in the approaches of different authors, but anyway, they all stress the importance of the presence of dynamic scheme in solving problems (see Chi & Bassok, 1989; Ferguson-Hessler & de Jong, 1987; de Jong & Ferguson-Hessler, 1996). Reusser (1993) even argues that there are to be formed three different mental models (interacted schemas): situational model (about problem situation), structural model (about the general structure of the problem), and algorithmic (about solving strategies) model. Mistakes in solving a story problem appear if there are errors in developing one of these three or in relating them with each other.

Jonassen (2003) has defined problem schemas, including both semantic and situational information about the problem, in association with the procedures for

solving particular type of problem. Marshall (1995) has studied the structure of story problems and described five different schemas with both semantic and situational information about the problem, forming the basis for selecting correct strategy for solving it. These schemas can be applied for overcoming the difficulties of the balance between the situation and data in the story. According to Marshall (1995), the five types of problem schemas are: i) quantity of something changes over time, ii) small groups have to be combined into larger ones, iii) comparing two things in order to find the larger or smaller, iv) restating the relation in terms of numerical values, v) applying a generalized relation in a new situation. Mayer (1982) has also developed schemas for story problems after analysing a big number of algebra problems. He has identified eight families of stories with sub-categories and developed different templates for solving them: i) amount per time rate, ii) unit cost rate, iii) per cent cost rate, iv) straight rate, v) geometry (simple area), vi) physics (Ohm's law), vii) statistics (combinations), and viii) number story. Both, Marshall's and Mayer's schemas have been found on the basis of mathematical problems; however, there is much transferable into story problems in biology, which is our interest. For instance, quantitative changes in environmental and ecological context are often discussed as changes over time compared with normal levels of pollution, population size, etc. Nevertheless, in many cases, the problems of biology are more complex and these schemas have to be integrated. Therefore, in the domain of biological story problems, the importance of skills to analyse and synthesise different information from the current story, previously solved problems, and known algorithms and templates increases compared with math.

However, independently from the context domain, the classification of a story problem is the first crucial stage in problem solving. Many studies (Chi et al., 1981; Silver, 1981; Rogoff & Lave, 1984) have demonstrated that novice problem solvers tend to classify problems on the basis of situational characteristics while experts do it using structural ones. However, the experienced problem solvers may sometimes only focus on the structural characteristics and, therefore, give an answer that is situationally impossible (Hinsley et al., 1977). The best solution for defining the story problems is to integrate structural and situational characteristics and animate the situation (Nathan et al., 1992). Nathan et al. (1992) studied the performance of solving story problems in applying a computer-based learning environment ANIMATE that provided students with an animated representation of the problem and, therefore, they learned how to associate situations with formal expressions.

In the context of biology, the findings of Lucangelli et al. (1998) are in general more applicable. They have distinguished five capacities that are required for solving story problems effectively: i) semantic comprehension of relevant textual information, ii) the skill to visualize data, iii) the capacity to recognize the deep structure of the problem, iv) correct sequencing of the activities in solving the problem, and v) the capacity and willingness to evaluate the procedure applied for problem solving. The first idea represents the analysis

of textual information, the second one describes the skill to analyse visual data and translations between visual and non-visual information, and the third item handles with combining all together into understanding the problem in a broad context. It is essential to understand the ‘deep structure of the problem’ for classifying the problem correctly and it is a premise of transferring problem solving skills from previous analogical cases or to the problem tasks that will be solved further (Mayer et al., 1984). Chi et al. (1981) studied the categorisation of physics problems and found that experienced solvers relied more on conceptual models of the problems’ structural characteristics, rather than quantitative models represented in formulas. It demonstrates that the comprehension of the textual or visual story, not numbers, is the crucial element in leading successful problem solving. The fourth capacity — sequencing the activities — directs learners to carry out the experiments that have to be evaluated according to the fifth point after making any conclusions.

Jonassen (1997) inferred on the basis of Gagne (1985) and Bloom et al. (1956) that problem solving would require a combination of analysis and synthesis skills, though these are not always specifically identified. However, problem solving is more complex than a simple sum of all its components and, therefore, it has to be evaluated not only through skills to analyse and synthesise but also on the basis of the general outcome of the process. Therefore, the present research assessed both students’ general outcome of problem solving and their analytical skills. Analysis of visual information — graphs, figures, photos, and tables — helps students to acquire knowledge about principles and phenomena that are hard to understand on text-based descriptions only (Lee & Nelson, 2004). These provide students with a visual representation of the processes under investigation and, therefore, the objects in each particular process can be more easily related with each other. However, Abrams et al. (2001) have demonstrated that only one third of secondary school students are able to interpret graphs correctly, although the graphs are more organised presentations of data than tables, figures or photos. It means that more attention should be paid to analytical skills in the process of problem solving.

The skills of problem solving can be divided into general and domain specific (Taconis et al., 2001). General skills relate to the general activities of the problem solving strategy: identifying a problem, formulating research questions and hypotheses, analysing, planning, and doing calculations. According to Grayson’s work (1996, 1997) general skills of problem solving also involve thinking skills like proportional reasoning and Savelsbergh (1998) adds skills for building an adequate mental representation out of the schemata available. Domain specific skills are often derived from the specific methods applied for example in biological research. Therefore, these are not general and not transferable from one context to another (Taconis et al., 2001).

In order to clarify the characteristics of effective problem solving, the activities of novices and experts have to be compared. Speed, fluency, and perfection of the cognitive activities are typical for experts whereas beginners

tend to be slow and hesitant and they make errors and mistakes (Taconis et al., 2001).

Problem solving skills applied by experts in solving story problems can be derived from the detailed steps of solving them (see Jonassen, 1997, 2000, 2003):

- Clarifying goals or expected outcomes;
- Identifying the types, sub-types, and schemas of problems;
- Memorising analogical cases and analysing similarities and differences of these particular problems;
- Selecting and applying appropriate algorithm for solving the present problem;
- Identifying dependent and independent variables in the story (either texts or visual representations);
- Assigning values to the algorithm;
- Implementing tools or other equipment for solving that problem;
- Applying the strategy carefully in avoiding possible mistakes;
- Interpreting the results in the light of the problem situation;
- Regulating all activities, including evaluation of problem solving process in all stages.

In addition to problem solving skills, an effective problem solver has to have different types of knowledge: i) knowledge of problem situations, ii) conceptual knowledge, iii) procedural knowledge, and iv) strategic knowledge (de Jong & Ferguson-Hessler, 1996 refereed from de Jong, 1986). The first one is related to the situation awareness (Kentridge & Heywood, 2000) — students' knowledge about the attributes of the actual situation (de Jong, 1986). Conceptual knowledge is domain-related and involves all facts and principles needed for solving a particular problem. Procedural knowledge comprises all knowledge about activities that should be performed in order to solve a problem. The last one, strategic knowledge, embraces metacognitive knowledge — all that is needed for leading and controlling the whole process of problem solving. The meaning of conceptual knowledge is in some newer works also used as the concept of declarative knowledge that indicates familiarity concerning facts, principles, and laws of the discipline for drawing conclusions about the situation and for executing the solution (de Jong & Ferguson-Hessler, 1996).

The influence of computer simulations has been evaluated on the definitional, intuitive, and structural knowledge as well (de Jong et al., 1999). Definitional knowledge represents students' understanding of the facts and concepts of a particular domain and, therefore, it might be used as a synonym for conceptual knowledge. Intuitive knowledge implicates students' success in acting in accordance with certain conditions and predictions. It is comparable with the knowledge of problem situations and procedural or strategic knowledge (see de Jong, 1986). The third type — structural knowledge — indicates students' ability to relate various concepts of the particular domain

with each other (de Jong et al., 1999). It stresses a significant aspect that integrated usage of different concepts is important in problem solving.

In the current research, we were especially interested in general, not domain-specific skills that are transferable from the school biology into other domains. Although applying these skills is indefinitely related to certain types of knowledge, the knowledge itself was not under investigation in the present case.

2.1.3. What is inquiry learning?

Inquiry learning has been closely related to discovery. Zachos with co-workers (2000) has extensively studied the capabilities and skills needed for effective discovery and defined that scientific discovery learning is ‘the self-attained grasp of a phenomenon through building and testing concepts as a result of inquiry of the phenomenon’ (Zachos et al., 2000, p. 942). Inquiry learning can be defined as ‘the process of discovering rules governing relations between dependent and independent variables based on experiments in which independent variables are manipulated’ (Wilhelm, 2001). On the other hand, inquiry learning can be characterised as a process of understanding an observation or solving a problem that involves a process of exploring the natural or material world and leads to asking questions, making discoveries, and rigorously testing these discoveries in the search of new understanding (National Science Foundation, 2000). Anyway, on the basis of these definitions it can be concluded that the aim of scientific discovery is finding new relations on the basis of inquiry, or inquiry is a process of investigating these relations and it ends with making a discovery. Problem solving is closely related to these concepts but is a more general activity. Inquiry learning can be regarded as one method among others for solving a problem. The high level of inquiry skills enhances students’ achievement in the aspects of problem solving skills, ability to explain data, critical thinking, and understanding of principles in learning science (Chiappetta & Russel, 1982; Saunders & Shepardson, 1987; Haury, 1993). In the current research, the concepts of problem solving and inquiry learning are integrated with each other and scientific discovery is used as a synonym for inquiry learning.

The process of scientific discovery has been studied for about fifty years, starting with the research of Bruner et al. (1956) who were interested in the concept of discovery. Popper (1959) defined it through two consequent activities — building scientific concepts and testing them. The first stage deals with formulating research questions and hypotheses according to initial observations and background information. The building of scientific concepts by learners requires inductive, creative, and imaginative activities (Nersessian, 1999). The testing stage starts with experimenting in order to test the hypotheses. The second stage ends with making a new statement — a

generalisation about a natural phenomenon where systematic hypothetical-deductive reasoning and application of different general methodological rules are needed (Popper, 1959). All these activities — formulating research questions and hypotheses, experimenting and analysing the results and making generalisations require certain inquiry skills.

Although Bruner's, Popper's and some other authors' concepts were introduced about half of a century ago, these ideas started to spread into curricula and instructional programmes either classroom-based or computer-based more than thirty years later. The new era started when the ideas of Popper were developed in Klahr and Dunbar's (1988) theory 'Scientific Discovery as Dual Search'. This theory states that scientific discovery is dual search between hypothesis space and experiment space. These two spaces can be compared with Popper's stages of building and testing scientific concepts. However, according to Klahr and Dunbar's idea these stages have not to be followed in a certain order. Even more, they have demonstrated that searching in hypothesis space is guided not only by prior knowledge but also by experimental results. Sometimes learners start the processes of discovery with posing the hypothesis and after the first unsuccessful experiment turn back to forming a new hypothesis whereas in other cases they carry out many experiments without generating new hypotheses. Klahr and Dunbar (1988) also proposed that there are two types of learners: experimenters and theorists. The learners, belonging to the first type, formulate a correct rule even if they search only in the hypothesis space whereas the others cannot manage without experimenting. Besides, in many situations there is a continuing interactive search between the hypothesis and experiment space — between theory and evidence. When students have a hypothesis, they will control it with empirical results and when they have the results, they will have to check if these contribute to the hypothesis and theory.

Recently, inquiry learning has been defined as an educational activity in which students investigate a set of phenomena and draw conclusions (Kuhn et al., 2000). This is probably too broad approach as investigating a set of phenomena can be interpreted, as working in problem space and conclusion is comparable with problem solution. Still, it demonstrates a relatively strong connection between these approaches.

In a general manner, the processes of inquiry learning are divided into transformative and regulative ones (de Jong & Njoo, 1992). Transformative processes lead a learner towards the solution of a problem step by step whereas regulative ones are necessary for planning, monitoring, and evaluating transformative processes. It means that in inquiry learning, two parallel sets of actions are carried out and concentrating only on one of these could lead to unsuccessful problem solving. However, according to other authors, the regulative processes are embedded into the list of transformative ones and, therefore, we describe the steps of inquiry in one sequence.

Table 1 presents a survey of different theories about inquiry or discovery learning. The first column of the table generalises the different steps of inquiry learning proposed by different authors. It is demonstrated that the start and endpoint is not always the same for different approaches. If the process commonly starts with getting acquainted with the situation or story in the terms of story problems then Friedler et al. (1990) begins with defining a scientific problem that is normally the second step in this sequence. The second significant difference appears in the endpoint that is, in many cases, analysis and interpretation of results, which is as a basis for solution of the problem. In the work of Padilla (1990) and Harlen and Jelly (1997), there is an additional stage of presenting the findings to others in the learning community. Nevertheless, it is reasonable to add that stage because it is not sufficient if somebody knows an answer to a problem but cannot make it understandable for the others.

Rivers and Vockell (1987) proposed a theory that adduced three important stages of inquiry learning: plan, execute, and evaluate. Yet, the usage of these terms is too minimal for reflecting the complexity of the process and, therefore, an extensive explanation of these steps is needed. In this context, planning means everything that is needed for designing an experiment: getting acquainted with problem situation, defining the problem, reading background information for formulating research questions and educated guesses (hypotheses), and developing reasonable strategies for controlling them. Executing only contains actual experimentation and data collection, while all analysis and interpretation already belongs to the stage of evaluation. Although this distinction embraces almost everything from the other classifications, it is too general for applying in deeper analysis of inquiry process.

Padilla (1990) has proposed an exhaustive classification of inquiry steps making a distinction between basic and integrated science process skills. At the basic level, students have to observe, infer and measure, communicate in analysing and presenting data, classify information about objects and events, and predict what might happen in a new situation. Integrated science process skills involve formulating research questions and hypotheses, planning and carrying out experiments, interpreting data, and composing models as generalisations about the process that are investigated. He also argues that the skills of these levels — basic and integrated — have to be mainly developed by different groups of learners. Basic skills are developed especially in the case of students whose mental operations are mainly on concrete level and integrated skills are for abstract thinkers. The distinction between concrete and abstract thinking was demonstrated a long time ago by Piaget (1929).

The most appropriate sequence of inquiry learning steps is presented by Harlen and Jelly (1997). They have divided that complex process into seven stages: observing, questioning, hypothesising, predicting, investigating, interpreting, and communicating. This approach generalises the ideas presented in a number of other works (see Table 1). In addition, they also provided the

stages of inquiry with extensive descriptions, applicable in evaluation the inquiry skills in detail.

Table 1. The stages of inquiry based on various research papers on discovery and inquiry learning.

Stages of inquiry	Klahr & Dunbar, 1988	Rivers & Vockell, 1987	Veer mans, 2002	Harlen & Jelly, 1997	Friedler et al., 1990	Padilla, 1990
Identifying the problem	hypothesis space	planning (designing experiment)	orientation	observing		observing
						classifying
Formulating research questions				questioning (raising questions)	defining a scientific problem	controlling variables
Formulating hypotheses			stating hypothesis	hypothesising (explaining)	stating a hypothesis	formulating hypotheses
Planning the study	experiment space			predicting (planning investigations)	designing an experiment	classifying
						predicting
						defining operationally
Executing the plan		executing (carrying out experiment, collecting data)	controlling hypothesis	investigating (conducting investigations)	observing	experimenting
					collecting data	measuring
Analysis and interpretation of results		evaluating (analysing data and developing hypothesis)	making inferences	interpreting (interpreting evidence)	analysing and interpreting data	interpreting data
					making predictions on the basis of the results	inferring, predicting
					applying the results	classifying
Representing findings				communicating		formulating models
						communicating

In the table, ‘identifying the problem’ contains skills for watching carefully, taking notes, identifying similarities and differences, seeing patterns, and understanding the order in which the events have taken place. ‘Formulating research questions’ includes aims of determining how to turn non-investigable questions into investigable ones, to understand which questions can be answered by experimentation, to recognize the questions that are generative, long lasting, and interesting enough to foster a rich investigation. On the basis

of these descriptions and in comparing them with the discussion about problems, we can generalise that a real inquiry process always starts with a certain type of problem — a problem that can be solved with investigation. ‘Formulating hypotheses’ means providing explanations consistent with available observations, questions, and evidence. Correct hypotheses have to be controllable with an experiment. The step of ‘planning the study’ contains using evidence in recognizing patterns in data from which to extrapolate or interpolate in order to select more useful and testable hypotheses and algorithms. The next stage, ‘executing the plan’, is divided into the steps of planning, conducting experiments, measuring, data gathering, and controlling variables. It is the stage that is overlapping with the step ‘planning the study’ in this distinction. ‘Analysis and interpretation of results’ implies making sure that the data supports the hypothesised connections, synthesising, finding patterns, relating findings to initial questions and observations, and drawing conclusions. The final stage in inquiry process ‘representing findings’, means demonstrating the results in a clear manner, choosing the appropriate way to translate the outcomes to others, making representations such as charts or diagrams that illustrate data and results, talking to the others about the whole study, but also listening to the others’ evidence and explanations.

A complete overview of assessing scientific inquiry and discovery in classroom-based activities has been made by Zachos et al. (2000). They differentiate the measures that characterise ‘Scientific Inquiry’ and these that relate to ‘Scientific Discovery’. They both are essential for successful inquiry learning process because the first group displays the skills that have to be applied in the process of carrying out research and the second group outlines the skills for formulating decisions and making generalisations on the basis of inquiry process. Zachos et al. (2000) argue that there are many inquiry capabilities of students that could not have any effect on formulating new laws, principles, and rules about natural phenomena. The latter process is defined as scientific discovery in their study. Therefore, according to this approach, inquiry skills should be evaluated through the success of discovery. It means that inquiry is a process for finding a relation (making discoveries) and discovery is a process for controlling if this particular relation is applicable with success in a new experiment. The final discovery has to be made after both processes.

Zachos et al. (2000) have distinguished ‘science process skills’, ‘problem-solving skills’, ‘scientific method’, ‘scientific thinking’, ‘critical thinking’, and ‘reflexive thinking’ for proposing 29 inquiry capabilities. These were divided into six sections (see also <http://www.acase.org/jrst>): fundamental scientific knowledge, theory building, theory testing, logical mathematical operations, values concerning phenomena and the world, and values concerning methods of approaching the world. Zachos and co-workers have applied interviews and video recordings that are useful for determining learners’ values and attitudes and some other possible factors of successful inquiry learning. It is also

understandable that evaluating all 29 capabilities requires a very complex research design and a lot of participants and/or similar studies. A small number of participants and the lack of different types of experiments (only three different experiments with 32 students) could be the reason why the workgroup of Zachos did not prove the statistically significant influence of many factors but only in the case of the most important ones. Therefore, we have selected for the current research five inquiry capabilities from different sections that have a statistically significant influence on discovering the rules of natural phenomena:

- Coordinating theory with evidence;
- Recording observations;
- Consulting recorded notes;
- Identifying the sources of error in taking measurements;
- Controlling variables.

The first capability is also introduced by Kuhn et al. (1988). They have demonstrated two types of integration between theory and empirical results. First, the evidence should be used for evaluating a theory, and secondly, the theory has to be applied for interpreting the data. The importance of 'recording observations' has been studied by Norris and King (Norris, 1984; Norris & King, 1984; Norris, 1985). They differentiate simple 'note-taking' from observations and a systematic activity in recording observations. However, sometimes learners make some notes during the experiment but do not use them in reasoning their judgements. In 'consulting notes', they distinguish applying recordings for recalling findings and referring these when presenting hypotheses and arguments. The capability of 'identifying the sources of error in taking measurements' has been formulated by Zachos et al. (2000) on the basis of the previous work (Lunetta & Tamir, 1979; Wise, 1995). They propose a four-level scale for evaluation of this capability: i) the learner does not raise the issue of possible sources of error, ii) raises that issue, iii) suggests possible sources of error in taking measurements, iv) identifies reasonable sources of error in taking measurements. The basic of the inquiry capability 'controlling variables' has been originally presented some fifty years ago by Inhelder and Piaget (1954). It comprises the idea that learners have to attempt to isolate the effect of one variable on the criterion by holding constant the effects of all other variables that could have an effect on the phenomenon under investigation. Novice learners often express the need of keeping some variables constant but fail in a real experiment, while experts pay more attention to the methods that should be applied for eliminating the influence of all other variables not under investigation in an actual study.

Taking into consideration the characteristics and solving strategies of story problems introduced in the former chapters, it can be concluded that inquiry learning is applicable for solving story problems searching relations between independent and dependent variables presented either in the textual or visual forms. In the present research, the main focus has been turned on this type of story problems in biology.

2.1.4. What characteristics influence inquiry-based problem solving?

Although the level of all problem solving and inquiry skills is very important in determining the performance of solving story problems, there are some additional aspects in order to get a complete overview of factors influencing problem solving. Smith (1991) has distinguished learners' external and internal factors. External ones implicate all that can be described among problem representation and the learning environment, while internal factors include individual characteristics of problem solvers.

Structuredness, complexity, domain specificity, and type of representation are the external factors of problem solving (Jonassen, 2000). However, these are characteristics of a problem and do not take into account the presence of a learning environment that frames the task. Therefore, the model of complex problem solving by Funke and Frensch (1995) has to be discussed. According to this, complex problem solving has been defined as interaction between a problem solver and a task in the context of environment. In this context, a learning environment involves all that surrounds the problem task: additional information, resources, disturbances, feedback, cooperation, peer pressure, etc. (see Brehmer, 1995). The task itself includes factors concerning the structure of the problem, transparency of the task, and context. The differences in the structure of a problem are elaborated in the former chapters. The transparency remarks the complexity of the structure of represented story. Contextual characteristics are divided into familiarity with the domain and semantic embeddedness of the problem solver into similar or analogical problems (see Huber, 1995).

The latest research on computer-based problem solving has demonstrated that while in classroom environment a teacher guides students towards experience then in multimedia-based environment the importance of a teacher is minimized and, therefore, the absence of such a facilitator is one of the most important factors that can cause the failure in learning with computers (Zhang et al., 2004). In addition, it has been demonstrated that not only the physical but also the social environment plays a very important role in problem solving or inquiry learning process. It means that the internal and external factors are interrelated and affect the outcome more than only the sum of them. A learner is in social interaction with other students in a collaborative learning group and with virtual facilitator or adaptive support mechanism of the computer-based learning environment. Moreover, in some studies the support of the environment that enhances students' situation awareness, either contextual or task and process, has been regarded as one of the most important factors influencing the computer-based learning process (see Veermans et al., 2000; Reid et al., 2003; Zhang et al., 2004, Pata et al., 2006). Contextual awareness involves learners' knowledge about the available resources and relations in the learning environment in which the problem-solving takes place. Task and process awareness can be explained as students' knowledge about why and how

they have to do something in order to achieve their goals (Sonnenwald *et al.* 2004).

Funke and Frensch (1995) divided internal factors into experience, cognitive variables, and non-cognitive variables. By Jonassen (2000) the experience indicates familiarity and knowledge, either concerning domain or structure of the task. It enables expert problem-solvers to apply problem schemas which can be employed more automatically while novices have to design this schema and may fail already in that stage (see Sweller, 1988).

The ‘cognitive variables’ in the classification of Funke and Frensch (1995) cover initial knowledge and skills concerning the problem task and context. Jonassen (2000) pays more attention to the terms of cognitive styles and controls which represent patterns of thinking and reasoning. We can also generalise that it means learners’ initial ability to solve story problems and to analyse various types of visual information presented in these stories: graphs, tables, photos, and figures. However, these cognitive variables embrace the skills to organize learning in small groups.

‘Non-cognitive’ factors that influence problem solving are students’ self-confidence, perseverance, motivation, and enjoyment (Funke & Frensch, 1995). Jonassen (2000) describes epistemological beliefs in the same context. It means that problem solving requires considering the veracity of ideas and multiple perspectives during evaluation of possible solutions. Therefore, problem solving always remains different for various types of learners, even after exhaustive instruction with extensive support. For example, Perry (1970) has distinguished nine separate stages of intellectual development clustered into three periods. In the first period, learners believe that knowledge is either absolutely right or wrong and there are no intermediate stages. In the second period, the extremeness of students accepts the multiplicity of ideas and methods and is sceptic in a final correct solution. In the third ‘period’, there are evaluative thinkers who accept the role of judgments and understand that experts provide better answers. The last group has the highest achievement in solving problems.

In conclusion, both types of factors influencing problem solving — external and internal — are considerably well studied. However, there is a lack of information concerning some aspects of both types: i) the characteristics of learning groups, and ii) the presence and type of support. Therefore, our research focused on these aspects.

2.2. Computer-based learning environments for problem solving

2.2.1. What describes an effective environment for improving problem solving skills?

The extensive intervention of computers into schools started at the beginning of eighties of the last century. It made it possible to present abstract objects, phenomena and processes in concrete visualised forms (Papert, 1980). The important educational revolution started thanks to developing a graphic interface for computers (Taylor, 1980). From year to year the value of computers and information technology in a broader sense has increased indeterminably, however, the virtual world can cause misunderstandings and estrangement from the real situations (Teodoro, 1993) and acting in real world without sufficient attention to actual risks (Bielecki, 2000). Hand-in-hand with the development of the features of computers, the design of learning environments has made a big progress. Already Levin and Waugh (1988) differentiated simple tools, simulations, games, and microworlds among the learning environments. Simple tools do not allow embedding into the process, games are extraordinary simplifications, and microworlds are collections of different learning facilities not applicable for guided learning process. On the other hand, simulations are regarded as most effective learning environments for developing students' problem solving skills (see Merrill, 1987; Reigeluth, 1992).

Simulations are learning programs that represent a manipulative model of real world (either in a larger meaning or any particular process or phenomenon) that is simplified according to the instructional needs of target audience (see Naylor et al., 1966; Alessi & Trollip, 1985; Njoo & de Jong, 1993). According to Simmons (1991), Shuell (1992) and Uretsky (1995) the advantages of applying computer-simulations are the following:

- Simulations enable to present dynamic processes in visualised form;
- They provide an opportunity to save the work and to give immediate personal feedback;
- It is possible to explore the objects on the computer screen and manipulate with them, make experiments;
- Learning process is individualised;
- Geographically isolated people can learn synchronously with each other in small groups;
- The experiments that would be impossible, too hazardous, time-consuming, expensive, not recognisable, etc. in real world are allowed;
- They open a variety of real data through databases on the Internet;
- Attention of learners can be easily directed to the requested information.

It has been proved that conceptual computer simulations can reveal a positive effect on the development of learners' inquiry skills and problem solving (see Shute & Glaser, 1990; de Jong & van Joolingen, 1998; Kuhn et al., 2000;

Abrams et al., 2001; Reid et al., 2003). On the other hand, many studies have demonstrated that the application of inquiry-based instruction is not a suitable option for many novice science teachers (Crawford, 1999; Huber & Moore, 2001; Wong & Wong, 1998). Therefore, in many countries the process of problem solving has shifted its focus from teacher-centred learning to creating student-centred learning environments. At the same time, it has to be remembered that the more degrees of freedom the learning environment has, the more self-regulative students have to be and the more they have to be instructional designers for themselves (Elen & Lowyck, 2000).

Web-based simulations give students an opportunity to explore virtual processes and phenomena of the world, manipulate variables, observe the effects of their operations, and make experiments to discover relations between variables (Alessi & Trollip, 1985). In addition, the advantage of web-based environment compared with more traditional real environment is that web provides learners with a great variety of databases and other information sources for educational purposes and it also enables researchers and teachers to record and analyse students' activities over a wide area of learners.

There are many good examples of educational software designed for developing inquiry learning and/or problem solving. Pryor and Soloway (1997) developed an inquiry learning package 'ScienceWare' that provides simulation tools for controlling learners' hypotheses. Tabak et al. (1996) have used 'BGuiLE' (Biology Guided Inquiry Learning Environment) which enables to learn biological problem solving through scientific exploration. Linn and Slotta (Linn, 2000; Slotta & Linn, 2000) have introduced 'KIE' (Knowledge Integration Environment) for supporting students' problem solving activities with specific tools. All these are excellent for individualising the learning process. Harper (1997) has demonstrated in applying environmental simulations 'Investigating Lake Illuka' and 'Exploring the Nardoo' that web-based inquiry has a significant influence on improvement of students' problem solving skills. In these simulations, students get the access to real databases about natural ecosystems but they have no guidance for solving problems. Corderoy with co-workers (1993) also showed the increase of the higher order cognitive skills, which are important for solving problems. He demonstrated that the skills to analyse, synthesize, and evaluate different kind of information mainly develop due to applying inquiry learning programmes. Gimblett (2001) has described a study about the design of a simulation system for analysing the complex human-environment interactions in dynamic settings and concluded that learning to solve complex problems without self-directed exploration is not possible. However, it is pointed out in many studies that a web-based simulation environment does not have a positive effect on learning scientific concepts and skills comparing the effects with those of more traditional methods (see de Jong & van Joolingen, 1998; Lee, 1999). De Jong and van Joolingen (1998) have found four categories of reasons for that: i) difficulties in generating and adapting hypotheses, ii) poorly designed experiments, iii) difficulties in data

interpretation, iv) problems regarding the regulation of discovery learning. Therefore, the question of how to support the learning process in order to increase its effectiveness has been raised.

Web-based learning environments are virtual not real and, thus, there is another obstacle in applying them — how to make the knowledge and skills acquired in a virtual situation transferable into real situations. Mayer (1999) argues that although the search for problem solving transfer has a long and fruitful history (see Mayer & Wittrock, 1996), there is still a need for determining the conditions under which the advantages of multimedia environments lead to the highest level of problem solving transfer. In this context, multimedia environments are these in which instructional material is presented in multiple forms of representations (verbal and visual). This definition leads us towards an important advantage of computer-based learning environments — opportunity to combine different types of representations, even dynamic ones. Clark's and Paivio's dual coding theory that affirms the presence of separate visual and verbal information processing systems emphasises the importance of this possibility (Paivio, 1986; Clark & Paivio, 1991). The multimedia environments allow learners using different types of representations according to their needs and relate these types with each other. In addition, a computer-based learning environment enables us to use tools for organising and structuring the information and data gathered during solving the problems and, therefore, decreases the problems derived from the limitations of the visual and auditory working memory systems (Baddeley, 1992; Chandler & Sweller, 1991). Based on these ideas, Mayer with co-workers carried out a great number of studies (Mayer, 1989; Mayer & Gallini, 1990; Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994; Mayer et al., 1995; Mayer & Moreno, 1998; Mayer & Moreno, 2002) and found the following principles that have to be underlined in designing multimedia environments for better transfer from virtual situations into real ones:

- Learners receive words and corresponding pictures rather than words alone;
- Words and corresponding pictures are near rather than far from each other;
- Words and corresponding pictures are simultaneous rather than successive;
- Words are presented as a narration rather than as on-screen text;
- Few, rather than many, non-verbal sounds are presented;
- Visual and verbal segments are short rather than long;
- Extraneous material is excluded rather than included;
- Stronger design effects are proposed for low- rather than high-knowledge learners;
- Stronger design effects for high-, rather than low-spatial learners.

However, inquiry, discovery, or problem solving with computer-based environments does not happen in the assumptive way without any guidance (de Jong et al., 1999; Reid et al., 2003; Quintana et al., 2004). The support for learning without a teacher has to be similar to that what a teacher provides plus there has to be increased awareness of the learning environment and learning process

itself. The importance of these domains has extensively increased during the last years and this is also one key interest in this thesis.

2.2.2. How to support a web-based learning process?

Computer-software is applicable to help learners succeed in more complex tasks than they could otherwise master (Edelson et al., 1999; Davis & Linn, 2000; Reiser et al., 2001). It is possible while in a learning environment the students can be provided with two types of tools — cognitive and metacognitive. The cognitive tools (van Joolingen, 1999) have been defined as the instruments that support or perform cognitive processes for learners in order to support learning. They help students make experiments that are almost not feasible in real world or perform simple calculations or data analysis. Therefore, students can pay more attention to the interpretation of investigated phenomena or principles.

Metacognitive tools (Kentrige & Heywood, 2000) help students manage their learning process. Meta-cognition has been defined students' self-regulated control and guidance of the learning process (Flavell, 1976). It contains learners' knowledge about the learning process: 'Why am I learning?', 'What am I learning?', 'How am I learning?', 'How and what can I learn from the available materials and with appropriate tools?' (Flavell, 1979; Kentridge & Heywood, 2000). It has also been clarified by Reid et al. (2003) that only meaningful learning in a simulation environment can direct a learner to preferred learning outcomes. Metacognition can be regarded as a prerequisite for meaningful learning and, therefore, Jonassen (2000) also selects it as one internal factor influencing problem-solving outcome.

Scaffolding can be regarded as a key method for supporting learning in web-based environment, in which students can learn by taking increasing responsibility and ownership for their role in complex problem solving with the structure and guidance of more knowledgeable mentors or teachers (Collins et al., 1989). The learning programme can provide: i) prompts to encourage or remind students which steps to take (Davis & Linn, 2000), ii) graphical organizers or other notations to help students plan and organize their problem solving (Quintana et al., 1999), or iii) representations that help learners track which steps they have taken (Collins & Brown, 1988; Koedinger & Anderson, 1993). In all these cases, the software provides additional assistance to the basic task that could be too complicated for solving by the students without the support.

Doornekamp (2001) argues that taking up certain instructions in teaching-learning packages, including web-based environments, can develop learners' meta-cognitive skills that promote problem solving, e.g. making notes, drawing up study questions, adding teaching material, marking parts of the text, forming verbalisations and actions, and explaining concepts. However, different learners have to be supported in a different way as to the content and frequency of

support. According to the findings of Doornekamp (2001) an internal strategy, by which guidance has to be given in the problem, is effective for field-dependent students and those who are not fearful of failure. Less or no guidance is effective for field-independent learners and those who are positively fearful of failure. Design specifications related to an internal strategy can involve: i) structuring with the help of a model for problem solving, ii) varying instructional methods (oral versus written), iii) varying instructional characteristics (concrete versus abstract instruction), iv) varying the order of instruction (fixed versus self-paced order), v) varying the amount of written instruction (highly essential, moderately detailed, and highly detailed). An external strategy for guidance is added as an expedient to existing teaching-learning packages (Doornekamp, 2001). Design specifications related to an external strategy can offer a chart or worksheet with a systematic approach to problem solving, offer instruction in advance about an approach to problem solving and handling co-operative learning.

Students' meta-cognitive skills relate strongly with situation awareness. It has been demonstrated that situation awareness is the main factor that leads learners due to successful metacognition towards successful problem solving (Jonassen, 2000). Endsley (2000) has found in a meta-analysis that situation awareness is linked to performance outcomes in coordinating complex tasks, establishing mutual confidence, drawing attention to scientific details, developing a working understanding of new concepts, and synthesizing results into new knowledge. These activities are also characteristics of problem solving and inquiry learning. Therefore, we have to take into account learners' situational awareness in reasoning the effectiveness of learning to solve story problems. In the domain of computer-based environments, Gutwin and Greenberg (2002) have used the term 'workspace awareness' indicating the awareness of how people interact with the virtual environment and its tools integrated in a workspace. The latter is comparable with 'problem space' in the domain of problem solving. However, workspace awareness could be introduced as a part of a more widely used term of situation awareness and, therefore, in the current research only situation awareness has been under discussion.

Situation awareness comprises contextual, task and process, and socio-emotional information (Sonnenwald et al., 2004). It means that it is possible to handle three types of awareness. Still, in the context of computer-based learning environments contextual awareness, and task and process awareness are more important whereas socio-emotional awareness is important in real-life or collaborative learning interactions. Contextual awareness means learners' knowledge about the available resources and relations in the learning environment in which the activity — problem solving or inquiry learning — takes place. Task and process awareness can be explained as students' understanding of why and how they have to complete various steps in order to achieve their goals (Sonnenwald et al., 2004). According to these descriptions, it is necessary

to provide different support for the learners who have no complete overview about the information and tools in a virtual reality and those who are well aware of the resources but do not realise why these things are presented, in which way to get something necessary from these and how to operate with them. It indicates that some simple guidance has to be given for enhancing contextual awareness but a more complex step-by-step instruction has to be provided for supporting task and process awareness. The latter is similar to Reiser's (2004) structured approach that describes a systematic scaffolding method for helping learners to shape thinking in productive ways. He has demonstrated how the explicitness of representations and the ability to represent important conceptual aspects of a discipline in tools can play a role in structuring and problematizing learners' engagement with the subject matter.

Smith and Reiser (2005) have found that if observation is a starting point for problem solving and inquiry activities then students have to be provided with structured tasks that facilitate complex analysis and reasoning around observed materials. These tasks should help students understand that observation is a method of inquiry that gives data for articulating explanatory hypotheses and models. In addition, they propose that students have to be guided in order to re-examine their claims to look for potential confirmation biases that could weaken their explanations. The support for these activities can come from teachers, parents, and other knowledgeable peers but also from computer-based environments.

While web-based environments are generally designed for individuals, rather teacher-guided learning, students have to be provided with specific support in the programme. A great number of research papers has been dedicated to supporting problem solving and scientific inquiry over the last years (see Alessi, 2000; Veermans et al., 2000; Reid et al., 2003; Zhang et al., 2004) but only a few of them have paid attention to individualisation of the process on the basis of the real information about a particular learner or learning group — one of the essential advantages of using computers and web-based environments.

Edelson (2001) provides a framework 'Learning-for-Use' that can be used for supporting design of content-intensive inquiry-based science learning activities. The general aim of the theory is to integrate content and process together in the design of learning activities. It is composed for overcoming the inter knowledge problem (Whitehead, 1929) that will arise in many knowledge-oriented instructional programmes. They take into consideration that learning is happening through goal-directed knowledge construction that is guided by a combination of conscious and unconscious understanding goals and has to be usable further. Based on that, he constructs three steps for 'Learning-for-Use model': i) motivation that has to generate learners' need for gaining new knowledge, ii) knowledge construction as the actual learning process, and iii) knowledge refinement needed for organising and connecting knowledge structures. According to this model, the support for problem solving has to take

into account not only the learning process but also what is happening before and after that.

Quintana et al. (2004) have proposed a theory driven approach for developing a support system for inquiry learning environments. They have distinguished three main phases: (i) characterising cognitive tasks, interactions between learners and the tools in the environment and the artefacts that constitute the scientific practices of students, (ii) characterising the aspects of these practices in which learners have difficulties, (iii) characterising guidelines for support that specify ways which tools can alter the task to address the obstacles by trying to make tasks more tractable and productive for learners. The first one has to be taken into account already in developing a learning environment, while it has to be built in a way that can be described clearly, evaluated in application of it, and changed for finding the factors that have a positive effect on solving story problems. The second and third phases are important in the stage of formative evaluation of learning environments.

In contrast of supporting learners during the inquiry process itself, Veermans et al. (2000) have studied the effect of adaptive feedback in comparing pre-defined feedback. That kind of support is very valuable if we provide learners with many tasks and, therefore, the feedback for one solution can be applied in solving the next problems. In the study of Veermans et al. (2000), the adaptive feedback was designed on the basis of hypotheses and activities made during inquiry process by each learner whereas the pre-defined feedback was the same theoretical answer to each student. They have found that even if there are no differences in defining the concepts of physics and recalling equations, the experimental group has improved significantly more in understanding the processes and applying the knowledge in new situations. Besides, as an influence of the adapted feedback, the learners apply a more inquiry-based strategy for learning in comparison with the control group. It means that they know what, why and how to do in order to collect appropriate data with minimal time. This result indicates that the task and process awareness of the experimental group is higher and it has to be taken into account for increasing the effectiveness of inquiry learning.

Taconis, Ferguson-Hessler, and Broekkamp (2001) have carried out a meta-analysis for evaluating the characteristics of good and innovative problem-solving strategies. It supports the previously described approaches. Cognitive capacities and learning conditions are used as independent variables and standardised learning effect as the dependent one. This meta-analysis was based on 40 experiments that provided learners with guidelines and criteria that they could use in judging their own problem-solving process and products. They demonstrated that providing the learners with immediate feedback was an important prerequisite for the acquisition of problem-solving skills. They also found that group work had a positive effect only when combined with other variables, such as guidelines and feedback.

Another framework for developing a support system in computer-based learning environments has been proposed by Reid et al. (2003). They suggest that for increasing the effectiveness of discovery learning it is needed to apply three types of support in the simulation environments: interpretative, experimental, and reflective. Interpretive support helps learners to activate their previous knowledge and to relate this with different applications in the virtual environment in order to generate hypotheses and construct coherent understanding. Experimental support is necessary for guiding students during the planning process of a systematic and logical experiment or for interpreting the results. Reflective support increases learners' awareness of each step of the learning processes and prompts their reflective abstraction and integration of their inquiry. This study demonstrates that the interpretative support has a much stronger positive impact on understanding scientific processes and applying the gathered knowledge in new problem situations than the experimental support. The importance of the reflective support has been already proved by Zhang (2000).

An additional factor that influences learning outcome is the sequence of tasks. The importance of the sequence of the tasks has been already demonstrated by Landa (1974, 1976) in the context of mathematics and languages. Unfortunately, there are not known studies that combine a big number of different biological problems in order to evaluate the importance of the sequence of the tasks for different learners.

Finally, we have to draw some attention to the activity theory (Kuutti, 1996; Tessmer & Richey, 1997) that is an appropriate approach for developing instructional design framework for learning with constructivist learning environments like a problem-based learning simulation (Jonassen & Rohrer-Murphy, 1999). This theory declares that the teaching process has to be based on the interaction of human activity and consciousness (the human mind as whole) within its relevant environmental context and concepts, rules, or theories. According to this, an activity cannot be understood or analysed outside the context in which it occurs. In other words, in analysing human activity, we must determine not only the types of activities that learners apply but also the characteristics of learners who are engaged in this activity, what their goals and intentions are, what the outcomes of that activity are, the rules and norms that circumscribe it, and the larger community in which the activity occurs.

It can be concluded that the learning process supported in a web-based environment has to adapt to characteristics of the students. It means that in designing an effective learning environment we have to develop different support systems and provide different tasks (sequence of the tasks) for various types of learning-groups that are determined on the basis of their actual activities and performance in a similar learning situation.

2.2.3. Are there any advantages in solving problems by groups of learners?

In the present research, we were interested in problem solving that occurs in small groups and, therefore, we give an overview of problem solving and inquiry in collaborative situations. Learning in groups is one socio-cultural approach that could improve learners' performance through guidance and scaffolding (Rogoff, 1990), shared decision-making (Gauvain & Rogoff, 1989), intersubjectivity (Forman, 1992), and the presence of peers who motivate learning (Joiner et al., 1995). A distinction between collaborative and cooperative learning has been made. Collaboration involves the construction of meaning through interaction with other learners who are working in order to achieve a shared goal whereas cooperative work is emphasising the importance of dividing activities that have to be performed in order to reach the goal (Littleton & Häkkinen, 2003). In a collaborative activity, the members of a group are encouraged to support each other in achieving the shared goals of learning and, thereby, will also improve their individual skills and understanding (Slavin, 1996). Therefore, many researchers have been interested in studying the behaviour and effects of learning in groups situated into a virtual world by building environments for collaborative learning using computers (Mevarech & Light, 1992; Jehng, 1997; Chang et al., 1999).

It has been demonstrated that individuals facilitate the progress of a group by performing particular roles (Cohen, 1994) or implementing specific strategies (Barnes & Todd, 1977; Forman & Gazden, 1985; Cazden, 1988; Slavin, 1990). The common roles are: i) facilitator, ii) proposer, iii) supporter, iv) critic, and v) recorder. Facilitator invites participation, monitors the work, and promotes friendly discussion. Proposer has to be generating new ideas that will be evaluated and then supported or criticised by supporters and critics. Recorder is necessary for summarising the discussion. However, each learner may have various strategies for assuming one or other role and these may lead to effective or ineffective problem solving. Based on the number of roles, an effective group should contain up to five learners. Still, it is not always so because each member of the group may adopt various (all) roles in different parts of discussion (Chiu, 2000). Therefore, we have been also interested in how the size of the group influences the outcome of solving story problems.

The group work is theoretically more effective than the sum of individuals' actions. It has been demonstrated that learners who understand little about the immediate problem but work together cooperatively may generate multiple perspectives and coordinate them for synthesising a correct solution (see Stodolsky, 1984; Chiu, 2000). Students in a group can interact less or more cooperatively while working independently, displaying some of their information to others, explaining their ideas, comparing only their answers or even particular problem solving strategies. However, successful cooperation presumes that all stages of problem solving have to be discussed with each other

before going further (Chiu, 2000). According to that idea, learning in groups has a high potential in the field of learning complex problem solving skills.

Still, collaborative learning has another advantage compared with cooperative learning. While in the case of collaboration the learners are working all together at the same tasks, then they can scaffold each others' work (Littleton & Häkkinen, 2003). The factor of peer scaffolding is especially important when the activity of a tutor is lower or the tutor is missing (Pata et al., 2005).

Nevertheless, learning in groups embraces many hazards in it because it is a highly specialised form of communication in which students and teacher assume specific roles (Vygotsky, 1978). The teacher has to manage the learning environment, provide scaffolding, administrate the instruction, monitor the process, assess it and give relevant feedback based on the students' performance and needs. The students play an active part and assume more responsibility for their own learning and interact actively with their peers to enhance their learning process (Chiu, 2000). When students can cooperate or collaborate in such situations more or less similarly to real case then teacher is often absent in computer-based environments. However, there remains the problem that a computer can evaluate and apply in acting only the electronic representations of students' minds while a teacher has the possibility to monitor feelings, facial expressions.

There are also some difficulties concerning the formation of learning groups. Even among the members of voluntarily organised groups, individuals may interpret the problem situation differently and the advantages of shared knowledge and skills may turn in to disadvantages. The main characteristics that influence the performance of the group are gender (Berg & Calderone, 1994; Strough & Berg, 2000), age (Berg et al., 1998), and the nature of the relationship with others in the problem context (Strough et al., 1996). In the present study, we were especially interested in the differences derived from gender, while age is mainly important in comparing pre-school children with adolescents or the latter with adults; and the nature of relationship is not a general characteristic because it depends on context that is not the same in solving various story problems (Strough et al., 1996).

In studying the effects of gender, Strough and Berg (2000) have demonstrated that preadolescent girls use more high-affiliation strategies than boys in collaborative situations. Boys, on the other hand, often focus on dominance and asserting themselves at the expense of others (Leaper, 1991). Some other studies indicate similarities about different age groups (Gilligan, 1982; Sheldon, 1990; Fultz & Hertzog, 1991; Leaper, 1994; Jarvinen & Nichols, 1996; Rose & Asher, 1999). In addition, more effective collaboration also leads the groups of girls to higher level of performance in solving problems (Strough et al., 2001). It means that females are thought to be more orientated than males toward interpersonal concerns. Therefore, it is easier to apply the advantages of learning in groups that are formed from girls whereas the teams consisting of boys may need more guidance and support that is in classroom

provided by a teacher. Based on that idea, the groups of boys may need more support than girls in computer mediated learning. Nevertheless, a group where is one dominating boy and the rest are girls, may work perfectly according to the ideas of Strough and co-workers (2001). However, in general approach, Whitelock and Scanlon (1998) have demonstrated in the context of physics problem solving that female groups have significantly higher performance than male groups or mixed teams that reach almost equal outcome.

In current studies, the groups of learners formed voluntarily and they organised their work by themselves. It means that some of the groups consisted of only boys or girls whereas the others had a mixture of genders, thus the ratio of boys or girls in a group has to be an important characteristic in our analyses. On the other hand, it is not possible to say if students' work in groups was more collaborative or cooperative. Therefore, the effect of collaboration cannot be emphasised in the results and discussion.

3. METHODOLOGY

3.1. Design of the research

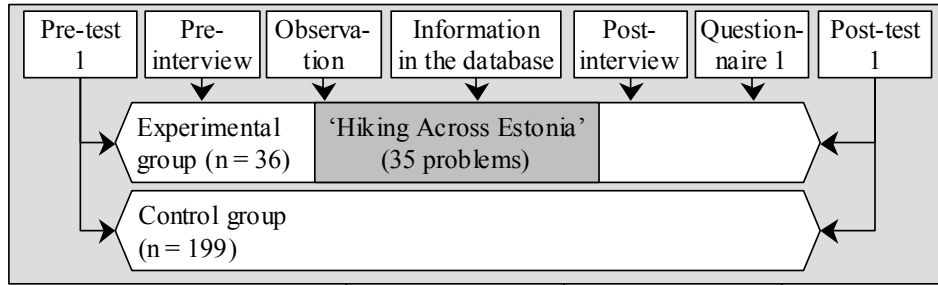
In general, the current research comprises three distinctive parts: the development and formative evaluation of the learning environment 'Hiking Across Estonia', the evaluation of students' problem solving skills in application of the environment, and the development of a support system adapted on the basis of different types of learners' groups.

Four different studies have been carried out for achieving these aims (Figure 1). In the original papers that form the basis of this thesis, we refer to these as the pre-study (see publication VII), main study (VI), first study (V, IV, III), and second study (III, II, I). However, in order to achieve a better understanding in this manuscript, we use Experiment I, Experiment II, Experiment III, and Experiment IV in the following chapters. A composing stage of the learning environment and the Experiment I (pre-study) took place in 2000 and 2001. Consequently, 'Hiking Across Estonia' was modified according to the results of the Experiment I and, next, it was applied in the Experiment II (main study) in 2002 that revealed a need for bigger changes in the problem tasks and tests for assessment of students' problem solving skills. These improvements were made by the year of 2003 when the Experiment III (first study) took place. The Experiment III enabled us to differentiate various types of learners' groups and to develop a support system containing the rearrangement of sequence of problems and supportive notes for enhancing task and process or contextual awareness. The support system was implemented in the Experiment IV (second study) in 2005. For all studies, except the Experiment I, all-Estonian competitions were organised. Students had to complete the virtual hike at their convenience during three (in the Experiment III and Experiment IV) or five weeks (in the Experiment I and Experiment II). The control group was only used in the Experiment I where it was possible to achieve the constancy of all treatments of experimental and control group, except the influence of learning environment 'Hiking Across Estonia'.

The participants of the Experiment I were 36 students from the 7th, 9th and 12th form in 9 groups that consisted of two girls and two boys from the same class who had initial problem solving skills on an average level of particular form according to a pre-test. Therefore, all learners of the classes of the sample filled in a pre-test before the selection of experimental group. The main objectives of this study were to carry out a formative evaluation of the simulation and to clarify its applicability by the students of different age. The design of that study has been extensively described and illustrated in publication VII. It had a very complex design that took into consideration the ideas of triangulation (see Schwandt, 1997; Denzin & Lincoln, 1998; Marshall & Rossman, 1999; Guion, 2002). Learners' problem solving skills were evaluated

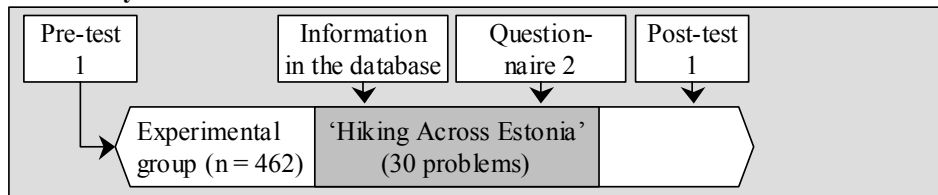
EXPERIMENT I

Pre-study



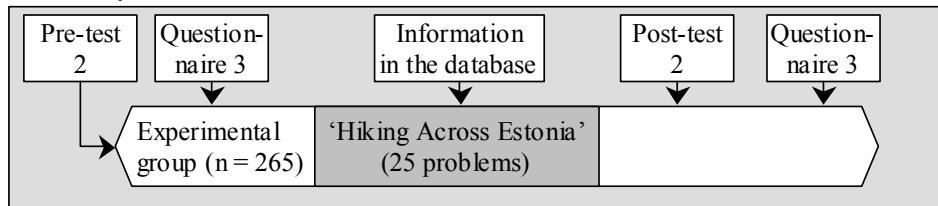
EXPERIMENT II

Main study



EXPERIMENT III

First study



EXPERIMENT IV

Second study

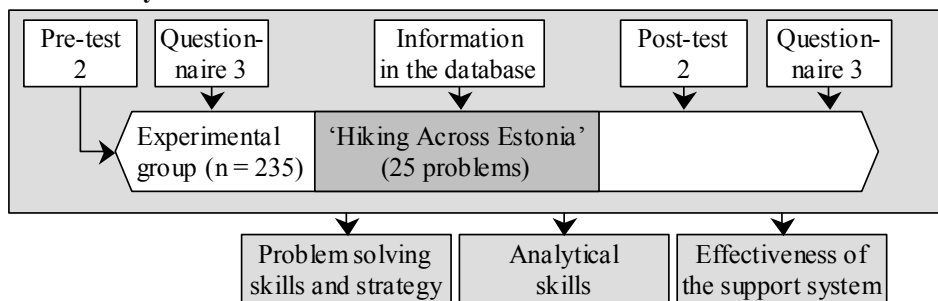


Figure 1. Research design of four experiments related to this thesis.

with a pre- and post-test, pre- and post-interview, and their answers to the 35 problems presented in the virtual hike that were saved into a database. In addition, the skills of collaborative learning were analysed on the basis of interviews and observations, which were made during all activities carried out in the learning environment. The third aim of the Experiment I was to evaluate the learning software itself and data for that were collected from questionnaires and observation during and after the application of 'Hiking Across Estonia'.

The Experiment II was designed especially for evaluating a change in students' problem solving skills and, therefore, it had a much simpler design. Still, it was accompanied with a short pre-study with 24 volunteer students from the 8th and 11th form but this was just for finding occasional snags and errors of the programme and for evaluating the suitability of all tasks to both upper basic and secondary school students before the learning environment was used in an all-Estonian competition (see VI). 111 teams of three to six people with 462 students from the 7th to 12th forms were extracted from this competition. These teams had completed the virtual hike and both pre-and post-test about problem solving skills. The outcome of solving 30 problems during 'Hiking Across Estonia' was also used for assessing learners' performance. In addition, the groups filled in a questionnaire for evaluating the difficulty level of problems in the virtual hike after solving each problem.

The Experiment III was carried out during an all-Estonian competition where 66 teams with 265 voluntary students from the 6th to 12th form filled in pre- and post-test and solved all 25 tasks of the virtual hike. In that study, a new pre- and post-test was developed for evaluating not only the students' problem solving skills but also their skills of inquiry learning (V, IV, III). In addition, a questionnaire for describing the methods of problem solving was provided to the groups of learners after completing the pre- and post-test (IV, III). Similarly to all others, the data saved in the database were also used in this study. However, in the current research, the characteristics of the learning groups, not only their results, were taken into consideration. That information was derived from the registration form completed before the usage of the environment: age, gender, number of members in a team.

One of the main findings of the Experiment III was that the level of problem solving skills in groups of learners was very different and there was a need for appropriate sequence of problem tasks and supportive notes. The Experiment IV was designed for evaluating the hypotheses formed on the basis of the first one.

It appeared in the Experiment III that it was possible to discriminate the groups of students based on their characteristics and initial skills in order to provide them with appropriate supportive notes and rearranged sequence of the tasks (III, II). In addition, a list of important factors that had a significant influence on solving web-based story problems was composed. It derived from the analysis of the information gathered from the Experiment III and Experiment IV. In the Experiment IV (also based on an all-Estonian competition), 235 students in 60 teams participated (III, II) and the selection of them was made for

the final evaluation of the factors influencing problem solving (I). Similarly to the Experiment III, the groups, which were formed voluntarily, were from the 6th to 12th forms. Nevertheless, there was an important difference in the design of the Experiment IV compared with the previous: the first four problems of the virtual hike were in the same sequence in both studies, while the following 21 problems were rearranged for two clusters out of five in the Experiment IV. Moreover, three clusters were provided with supportive notes for enhancing their contextual or task and process awareness. The support system was designed on the basis of learners-groups' differences (internal factors) in learning with web-based simulation 'Hiking Across Estonia' that provided students with problem tasks and all surrounded materials including those for developing their metacognitive skills through enhancing situation awareness. The approach of external and internal factors of Funke and Frensch (1995) has been used in designing the support system in this research (see Figure 2).

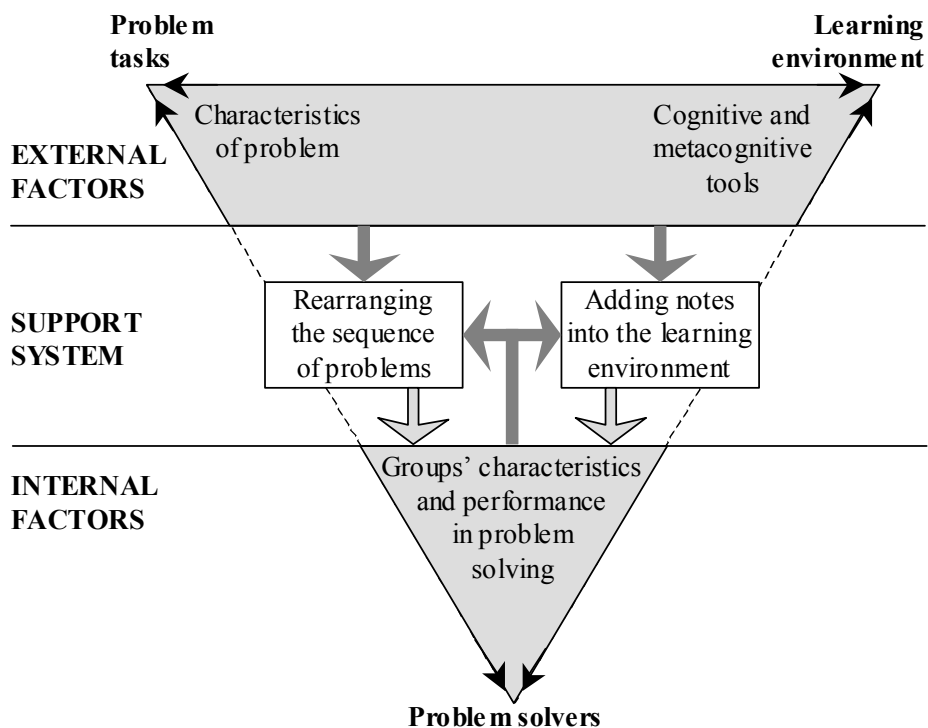


Figure 2. Composing principles of the support system of the learning environment 'Hiking Across Estonia' based on the relations between internal and external factors influencing problem solving (adapted from Funke & Frensch, 1995).

The groups' performance in solving story problems and their general characteristics like the number of members in a team, the ratio of genders, and the average age of students were used as groups' characteristics for providing various groups with appropriate support. Rearranging the sequence of the problems and adding supportive notes into the learning environment gave the support. In more detail, there were two types of notes — the first one for guiding students towards the usage of cognitive tools embedded into the learning programme and the second one especially for increasing their metacognitive skills through explaining how to operate in the learning environment with different available materials and virtual tools.

3.2. Learning environment

A web-based situational learning simulation 'Hiking Across Estonia' (<http://bio.edu.ee/matk/>) was developed in the Science Didactics Division at the University of Tartu. It was composed for developing learners' problem solving and inquiry skills in the context of biology without the guidance by a teacher. In designing the learning simulation, several theoretical aspects introduced in the previous chapters were taken into consideration (especially, Simmons, 1991; Shuell, 1992; Funke & Frensch, 1995; Uretsky, 1995; Jonassen, 2000). In addition, different curricula for science education were analysed (see Science Framework for California Public Schools, 1990; Scottish certificate of education: Higher grade. Arrangements in Biology, 1992; Scottish certificate of education: Standard grade amended arrangements in biology, 1992; Scottish certificate of education: Standard grade amended arrangements in science, 1992; Cambridge syllabus: Biological sciences, 1997; Cambridge syllabus: Structured science scheme: Biology, 1996; National science education standards, 1996; National curriculum for basic and secondary schools, 2002; National curriculum online, 2006). As a result of this analysis, a list of environmental and ecological themes that overlapped in various curricula was composed. These themes have been embedded into the story problems of 'Hiking Across Estonia' since Estonian curriculum is changing into the directions of listed curricula.

The programme can be divided into two parts: i) learning environment with tasks and all additional materials for learners, and ii) administrative pages for developers and researchers of the simulation. All users ask information through web-pages from the server, where Embperl programmes verify the user and act according to his/her information previously saved to the MySQL database (see Figure 1 in paper VI). In addition, some JavaScript actions are embedded into the html pages.

The pages of survey, registered hikers, organisers of the simulation, links to additional materials, and the map of the hike are available through the title page

of 'Hiking Across Estonia'. In addition, there is a registration form where a user chooses a unique user name and password for accessing the virtual hike. A link 'To hike' brings the registered user to the main page of the simulation that can be separated into two distinctive parts: the upper menu and main window. The first one enables to get a general help about the learning environment, to change personal data, to look at some statistics of virtual hikes, and to register teams for competitions. The main window is a gateway to the simulation itself. The user can select between different virtual hikes and enter the simulation.

Similarly to the main page, the page of the virtual hike can be divided into the upper menu and main window. The virtual map of the particular hike, the page of hiking teams registered to that hike, articles with additional information for solving the problems in this environment, reference page for finding usable external web-pages, and buttons for opening a problem solving task or quitting the environment are accessible from the upper menu. In the main window, a large photo of the ecosystem is presented. That represents the authentic place where the virtual hikers are and it is possible to open little windows with additional information about the species found in the background photo. In the upper right corner, the score of the simulation is presented and in the bottom corners there are the icons of sack and hut. The sack is for carrying food that can be eaten during the virtual hike and the hut enables to drink water, to buy some food that is not found in the nature, and to open some virtual tools that make it possible to solve some particular problems on the virtual hike.

A user starts with registration where he or she has to type name, birthday, gender, school, form, e-mail address, and choose appropriate username and password (see Figure 2 in paper VI). After that, it is possible to log into the learning environment where students get acquainted with five ecosystems: heath forest, grove, meadow, waterside meadow and bog. Each of them has a number of places where an ecological or environmental story problem has to be solved. The problems are presented in a certain sequence according to their type and content. Additional informative pages provide hikers with all the facts needed for solving problems. In the case of simple problems, only the information in this learning environment has to be analysed whereas in the complex problems a virtual tool have to be applied for collecting data that have to be used in addition to available information in texts and visuals. After solving each problem, students get immediate feedback about the correct and wrong answers. Some examples of the particular problems are presented in papers V, II, and I. All presentations of problems have been composed taking into consideration the aspects of situated learning (Lave, 1988). It means that first learners are situated into the authentic context in a particular ecosystem where a number of problems have been raised. For example, in one assignment they have to be young scientists who study the pollution of a river using the indicator species of invertebrates. Students are informed that somebody pollutes the water but no one takes the responsibility for it. This particular problem can be solved using additional data that have to be collected with a virtual tool. The story does not

involve these data but indicates the way it has to be gathered. Therefore, students must analyse the story taking into account some visualised data. This problem can be solved correctly if students have found the correlation between the numbers of various indicator species and levels of pollution and take into consideration the flow direction of the river as well.

In addition to the ecological and environmental problems, the groups of students are provided in the simulation environment with a virtual sack for carrying food. The 'food problem' appears along the whole virtual hike like in a real situation. The teams have to take some food from home at the beginning of the simulation and some from the nature. They also have some limitations in taking and eating food since the balance between various types of nutrients has to be achieved and poisonous plants or mushrooms must be avoided.

The number of story problems presented to learners was different: 35 in the Experiment I, 30 in the Experiment II, and 25 in both the Experiment III and Experiment IV. In the Experiment II, some problems were new in comparison with the Experiment I but in the Experiment III a selection of problems from the Experiment II with certain characteristics was applied. The tasks of the Experiment III and Experiment IV were exactly the same, while a completely new sample was formed for the Experiment IV. In the beginning (Experiment I and Experiment II) there was a bigger variety of tasks but in the Experiment III, the problems were developed according to an algorithm where in each of the five ecosystems the first problem mainly based on the analysis of textual information, the second on the analysis of photos, the third on the analysis of graphs, the fourth on the analysis of figures, and the fifth on the analysis of tables. However, some tasks were more complex and involved different types of analysis. First, all tasks embedded the analysis of texts but some of these were designed for analysing tables and graphs (1 task) figures and tables (3 tasks), figures and photos (1 task), figures and graphs (1 task), and figures, tables and photos (1 task). All on all, in the final version of the simulation 'Hiking Across Estonia', and the analysis of texts was performed concerning all 25 tasks, the analysis of figures, tables, and graphs seven times, and the analysis of photos in solving six story problems.

The sequence of the tasks on the virtual hike depended on the complexity and level of difficulty of each particular story problem. However, the initial difficulty level of five ecosystems of the learning environment was equal. Generally, there were four simple and one complex problem in each ecosystem. The complex one was always the last among these and enabled to carry out the whole inquiry process starting from identifying the problem, moving on to the analysis of background information, planning, data collection, analysis and interpretation of results, and presenting the findings. Solving the complex problem was always based on analysing different types of visual information. The four simple tasks were arranged within each ecosystem according to the level of difficulty, which was evaluated in the Experiment II. However, in the Experiment IV, the sequence of simple tasks was modified according to the

needs of various types of learning groups found with hierarchical cluster analysis. The ordinal number of the complex problems remained unchanged for comparing the results of the Experiment III and Experiment IV. As a result of this rearrangement, the difficulty of ecosystems was no longer equal.

The problems and surrounding additional materials and virtual equipment of the learning simulation can be handled together as a complex cognitive tool for improving students' problem solving skills in the context of biology. However, the learning environment also had a possibility to present text-based prompts to the groups of learners before each problem task. This option can be applied for supporting learners' situation awareness and, therefore, it is a metacognitive tool in our context.

And finally, the learning simulation made it possible to save different information into the MySQL database about each user's activities. The data that was applied in our studies comprised: i) students' age, ii) gender, and iii) form, iv) the number of members in each group, v) the ratio of boys among them, vi) the points learning groups got in solving story problems on the virtual hike, vii) the score for their answers in pre- and post-test, viii) the answers to story problems during the hike, ix) the answers in tests, x) the answers in questionnaires, and xi) time spent on solving each problem. Additionally, the information of log-files was analysed for purposes of formative evaluation.

3.3. Instruments

3.3.1. Questionnaires

Questionnaires are appropriate instruments for collecting information about learners' opinions and attitudes but also for getting explanations to students' actions (see Cohen et al., 2000). These are also applied for evaluating learning outcomes. We have applied them in both purposes in all four studies. In our case, the questionnaires for asking feedback from students are named 'questionnaires' whereas the questionnaires for evaluation students' knowledge and skills are called 'tests'.

Pre- and post-tests were the main data sources in this research. We developed two tests — the first for the Experiment I and Experiment II and the second one for the Experiment III and Experiment IV. The aim of both of these was to assess learners' general problem solving skill and their analytical skills. However, some disadvantages appeared in implementing the first test and, therefore, the second one was composed in order to carry out the final evaluation of the influence of using 'Hiking Across Estonia'.

The validity of both tests was evaluated through piloting that has been regarded as an effective method for controlling external validity of tests (see Oppenheim, 1992; Morrison, 1993; Wilson & McLean, 1994). In addition, the

help of experts' discussions was used in achieving the internal validity. The overall internal reliability was measured by Cronbach alpha test: that was 0.65 for the first pre-test and 0.59 for the first post-test, 0.76 for the second pre-test and 0.81 for the second post-test.

The first pre- and post-test consisted of six problem-solving tasks that were designed for assessing students' performance to solve story problems that presumed some particular type of skills — the analysis of texts, figures, and graphs. In addition to these, there was one task for assessing students' knowledge and understanding, another task for determining skills to relate different environmental domains, and one complex problem that involved all analytical skills evaluated by all other tasks. The tests were filled in within 20 to 30 minutes.

The second pre- and post-test were developed for the Experiment III and Experiment IV. In these tests, more questions were proposed concerning each stage of solving the problems in order to recall the process in detail for researchers and. It resulted in spending more time — about 30 to 60 minutes. Besides, in this case we were only interested in problem solving and analytical skills and, therefore, there were four complex tasks in both tests related to the analysis of texts, graphs, tables, photos, and figures. In the first two tasks, the groups of students had to detect and explain the relations between observed variables that were presented in graphs and tables (see Figure 3 and Table 3 in paper IV). They were asked to explain whether the variables correlated or not, and to argue their decisions. In the third task, two photos of the same forest or lake were presented to students (see Figure 2 in paper II). One photo was taken last summer and the other five years before. Learners had to find changes of the forest or lake that had already occurred, and to predict what could happen in the next five years. The fourth task was the most complex and embraced the analysis of figures and a short text, but within the inquiry process, learners also had to analyse a table that was filled in during data collection (see Appendix 1 in paper V). They were asked to find the correlations between different variables in an experimental and control group. Finally, learners compared their initial findings with the theoretical topic and developed their own explanations of this situation. They were also asked to find numerical correlations of three species in two ecosystems. The fourth task enabled us to evaluate the level of learners' inquiry skills (capabilities) because it contained appropriate sub-tasks: students had to record observations, consult recorded notes, reason concerning extreme cases, use co-variation as a basis for inferring causality, coordinate theory with evidence, and find possible sources of mistakes.

The questionnaires in the Experiment I consisted of two parts: i) evaluating each problem-solving task of the virtual hike, and ii) presenting their opinions about the learning environment as a whole. The opinion about each problem formed with filling in from 7 to 9 questions depending on the complexity of the particular problem. The second part of the instrument was composed on the basis of evaluation scale for educational web sites (Sarapuu & Adojaan, 1998).

There were 16 statements for evaluating ‘Hiking Across Estonia’ — 11 of these were programme specific and the rest domain specific. Students rated their agreement with each statement on a five point Likert scale (from 1 — completely disagree, to 5 — completely agree). For achieving the validity of the instrument, two questions evaluated the same item but one was composed in the positive and the other in the negative form.

In the Experiment II, a questionnaire was provided to the learning groups about their difficulties in solving each problem of the virtual hike. It had to be answered electronically before the hiking team was allowed to move on to a next story problem. It was similar to the first part of students’ questionnaire in the Experiment I.

A completely different questionnaire was applied in the Experiment III and Experiment IV. That was designed for obtaining explanations about the problem solving and inquiry strategies used in solving the problems of the pre- and post-test. It consisted of 11 items about the methods that learners had used in finding information or relations in visualised representations. They were also asked if they had made any hypotheses and notes during the analysis, tested all the hypotheses before making final conclusions, and how they had controlled the results before sending them to the database.

3.3.2. Observations and interviews

Observations were applied only in the Experiment I for formative evaluation of the learning environment. A structured observation is a required method if we have to know information that is usually not found in written questionnaires or that is staying in students’ minds during interviews (see Cohen et al., 2000; Johnson & Christensen, 2000). A structured observation with passive observers (see Spradley, 1980) was applied in our case. University students who were previously instructed about the objectives and methodology of the observation filled in a special observation form consisting of six questions about the applicability of ‘Hiking Across Estonia’ (including technical weaknesses), collaborative skills and changes of them in each group of learners (including emotional aspects), and the strategy that students applied in solving story problems.

Semi-structured group-interviews (see McCracken, 1988; Cohen *et al.*, 2000) were applied before and after the usage of learning simulation in the Experiment I in order to assess learners’ problem solving, analytical, and collaborative skills. The interviews were carried out by the author of this thesis and followed the suggestions of Cohen et al. (2000): i) preparation stage for getting acquainted with each other and for forming confidential and trustful environment, ii) introducing an environmental problem by the interviewer, iii) guiding students in revising their ideas and drawing conclusions. It was very important that the interviewer did not demonstrate any positive or negative

attitude towards the ideas of interviewees (see Johnson & Christensen, 2000). All interviews lasted from 35 to 50 minutes and were audio taped. The interviewer evaluated each interviewee's collaborative and analytical skills after each interview according to a three point Likert scale. In the case of collaborative skills, the mark '3' indicated a student who participated actively in group-work, took into consideration others' opinions, and did not try to dominate with own ideas. The other extreme ('1') was a student who did almost not participate in the work. The level of analytical skills was related to reasoning the statements. The level of problem solving skills was assigned to the group as a whole in a five point Likert scale. '5' characterised a group where students carried out a productive discussion with many sub-questions that had to be solved before making a final decision, and the final decision was a real compromise that took into consideration many advantages and disadvantages of particular solutions.

3.4. Data-analysis

All data from the observations and interviews were analysed only qualitatively in finding the frequencies of responses and comparing these between the groups or the groups' different stages of the study. However, the answers to tests, questionnaires and problems in the virtual hike were analysed quantitatively with a statistical package SPSS (Statistical Package for Social Studies) and, therefore, a deeper overview of statistical methods will be provided.

3.4.1. Evaluating learning outcome

The general evaluation of learning outcome was carried out in two different ways: i) comparing the results of pre- and post-tests with ANOVA or ANCOVA, and ii) estimating the change in students' performance during the virtual hike with Spearman rank order correlation analysis.

The analysis of variance (either co-variance) tells us if the means of two groups differ in a statistically significant manner and unlike the T-test, it takes into consideration the variance of both groups (see Kempthorne, 1952). Therefore, it was suitable for comparing the results of pre- and post-test, while in the post-test the variance usually changed due to the application of 'Hiking Across Estonia' between the tests. ANCOVA was implemented only in the Experiment II where the development of groups' skills strongly depended on the following characteristics (used as covariates) — learners' form, mother tongue, the number of group members, and their achievements in the pre-test (see papers VI, V, IV, and III) whereas ANOVA was suitable in the studies

where the influence of these factors was not very important (see papers II and I).

The sequence number of the tasks and the performance of students in each task correlated with Spearman rank order correlation. This method was appropriate because the number of story problems in 'Hiking Across Estonia' was big enough and there was a sufficient variance of the percentage gained from all points concerning each particular task. Still, the number of tasks and the diversity of points were ordinal characteristics with limited values and, therefore, Spearman correlation was applied rather than Pearson correlation (see Cohen et al., 2000).

In addition, some differences of learning outcomes in different clusters of learning groups were clarified with non-parametric tests. Kruskal-Wallis tests were used for finding statistically significant differences in the answers that the members of different clusters gave in the pre- and post-test, and for comparing learners' performance in the virtual hike. Wilcoxon signed ranks tests were carried out for finding general differences between specific answers in the pre- and post-test or questionnaires of problem solving strategies.

3.4.2. Detecting the types of learners' groups

One of the most important aims of our study was to differentiate the groups of learners for providing them with appropriate sequence of the tasks and supportive notes. First, the hierarchical cluster analysis was performed with all available data about the groups of learners of the Experiment III in order to develop the description of these clusters and a support system for the Experiment IV. Next, the clusters of new groups had to be predicted at the beginning of the Experiment IV and discriminant analysis was applied for that.

The cluster analysis is a widely used method for differentiating objects in evolutionary biology and analysis of the system of nature, and also in educational research (see Aldenderfer & Blashfield, 1984; Kaufman & Rousseeuw, 1990). Therefore, we were interested in applying that powerful method in the field of instructional design. It enabled us to use a list of variables for composing a cluster tree representing a visual model of the relations between the groups of learners (see papers V, II, and I). Next, it was possible to find the most important differences of these clusters in order to design a support system for each cluster. Students' answers in the pre- and post-test, data about their achievement and activities on the virtual hike, and general information about teams were used in clustering the groups of the Experiment III. The clusters were found according to the distance between different monophyletic groups identified visually in the cluster tree. Finally, the support system and appropriate sequence of the story problems in the virtual hike were provided to the groups of students in the Experiment IV.

The cluster, where the groups of the Experiment IV belonged, was predicted at the beginning of the study with the discriminant analysis (see papers II and I). In the analysis related to the paper I, all the results from the pre-test were not applied in order to make the student clusters independent of the test instruments. It was very important because it enabled to use the tests as the instruments for evaluating problem solving skills, while the prediction of clusters only remained on the basis of the actual learning process and personal information about the groups.

4. FINDINGS

The main findings of this thesis include four areas: i) the development of the web-based learning environment ‘Hiking Across Estonia’ and the evaluation of its applicability by students in acquiring skills to solve story problems, ii) the characterisation of the diversity of students’ groups who learn to solve problems in this web-based simulation — the findings from cluster analysis, iii) designing the support system for problem solving and inquiry learning in computer-mediated learning and, iv) the determination of the factors that have a significant influence on learning in small groups with web-based environments for solving story problems.

4.1. Evaluation of the learning environment

The results of the Experiment I demonstrated general applicability of the learning simulation ‘Hiking Across Estonia’ for the groups of students from the 7th to 12th form in developing their problem solving and collaborative skills. This conclusion based on the analysis of pre- and post-test, answers on the virtual hike (problem solving skills), and interviews and observations (problem solving and collaborative skills). The story problems were at an appropriate level of difficulty for all age groups since the students from the 7th form had an average achievement of 48 % and the 12th formers had 65 % (see paper VII). Only some minor changes were made either proposed by students or on the basis of their performance.

The general skill to solve story problems by the groups of students was evaluated in all studies. In the Experiment I, the level of problem solving skills was compared between the experimental and control group according to their results of the pre- and post-tests. The students, who had participated in the virtual hike, demonstrated a statistically significantly bigger improvement than their classmates not only in general problem solving ability but, also, in analysing texts, figures, and graphs (paper VII). Therefore, in the following studies, it was reasonable to pay attention only to a change in the experimental group. It was a very important aspect because other studies were based on all-Estonian competitions with voluntary groups and the control group for these was not available.

The results of piloting before the Experiment II were similar to the Experiment I — the average achievement in solving story problems was 49 % in the 8th form and 58 % in the 11th form. Only four problems out of 30 were regarded as too difficult whereas one problem was too simple. Some improvements were made to the help pages concerning the whole environment and virtual tools. On the other hand, students understood all the texts, graphs, figures, tables, and schemas of the learning environment clearly (paper VI).

The Experiment II (see paper VI) demonstrated a statistically significant increase in students' problem solving skills according to the ANCOVA ($F = 39.3$, $p < 0.01$). The same was concluded in the case of analysis of texts ($F = 4.3$, $p < 0.05$), graphs ($F = 71.2$, $p < 0.01$), and figures ($F = 4.8$, $p < 0.05$). The finding about general problem solving skill was verified by the analysis of the results in the virtual hike. Spearman correlation between the sequence number of tasks and general achievement was 0.337 ($p < 0.05$). It was interesting that the groups from upper basic school developed more than those from secondary school. It can be explained by the higher initial level of problem solving skills of the students from secondary school. However, after the usage of the learning environment the skills of the groups of these levels did not differ statistically significantly. One additional finding from the ANCOVA analysis was that the development of the skill to analyse figures did not depend on the same factors as the analysis of texts and graphs (initial level of these skills, students' form, number of members in a group, and their first language). Instead of that, it can be concluded that the analysis of figures is more difficult and can be only developed if the groups already have a certain level of skills for analysing texts and graphs.

In the Experiment III and Experiment IV, a new pre- and post-test and a set of story problems in the virtual hike were applied. The comparison of the results from tests with ANCOVA in the Experiment III (see paper V) indicated a statistically significant general improvement in solving story problems ($F = 15.0$, $p < 0.01$) and, also, in various analytical skills. A higher development occurred in students' ability to analyse story problems based on the analysis of graphs ($F = 37.5$, $p < 0.01$) and photos ($F = 18.6$, $p < 0.01$). A lower change but still at a high level of statistical significance involved the analysis of figures ($F = 11.9$, $p < 0.01$) and tables ($F = 7.5$, $p < 0.01$). However, these findings supported the results of the Experiment II that the analysis of figures was the most complicated skill, while the analysis of graphs was the easiest of all. In addition, we noticed that the skill to analyse photos improved similarly to the skills to analyse graphs whereas the analysis of tables seemed to be even more difficult than the analysis of figures. Moreover, the analysis of covariates demonstrated that the results mostly depended on students' initial performance in problem solving skills, their form, and gender. These outcomes directed us to the idea to control the development of different analytical skills by groups of students and, for that reason, we ran a cluster analysis for describing this process more specifically by certain groups of learners.

Next, the results of the Experiment III were analysed with the univariate analysis of variance (ANOVA) without covariates because we were interested in students' general performance first of all. Therefore, the general results concerning problem solving and analytical skills were considerably different (see paper II). The analysis of photos developed remarkably ($F = 32.6$, $p < 0.01$) while the analysis of tables progressed less than expected ($F = 4.7$, $p < 0.05$) and the analysis of graphs or figures did not develop statistically significantly at

all. In the following analysis, it appeared that there were only seven groups out of 65 who demonstrated their progress in all analytical skills and the others showed improvement in one or another particular skill. Accordingly, the idea from the Experiment III was derived — the results of the groups of students have to be analysed in certain clusters. In addition, it was predicted that providing these clusters with appropriate support would lead them to statistically significant development in all analytical skills needed for solving story problems. These findings are supported by the studies of de Jong et al. (1999), Reid et al. (2003), and Quintana et al. (2004) that computer-based learning is not in many cases with a higher effectiveness compared with traditional classroom based methodologies if we do not provide learners with appropriate guidance. In addition, the support system has to be adaptive because the groups are very different in their needs (Veermaans et al., 2000). As our results demonstrated, some of the groups would improve even in the most complicated skills and the others not even in the simplest ones.

In the Experiment IV, the groups of students were divided into five clusters on the basis of discriminant analysis and an appropriate support system was composed for each cluster. Some of these clusters were provided with different sequences of the tasks and supportive notes for enhancing their situation awareness. After applying that support system, the comparison of pre- and post-test demonstrated a statistically significant improvement of problem solving skills in all clusters (see Table 2 in paper I). Not all analytical skills developed in each cluster although these still improved at a high level of statistical significance among all learners generally (see Table 4 in paper II). The biggest improvement appeared in analysing tables ($F = 58.5$; $p < 0.01$) whereas the other types of analytical skills — analysis of graphs ($F = 20.5$; $p < 0.01$), photos ($F = 16.3$; $p < 0.01$), and figures ($F = 14.2$; $p < 0.01$) — developed less. Therefore, we can conclude that the learning environment ‘Hiking Across Estonia’ with the support system is applicable for all groups of learners in acquiring problem solving and inquiry skills.

4.2. Types of learners’ groups

The former chapter indicated the actual need for clustering the groups of students in order to provide them with appropriate support for learning to solve story problems. Therefore, we tried to determine ability characteristics of various groups for creating analogous groups with appropriate support in the second study. In our Experiment III, it was possible to distinguish five clusters of learners’ groups on the basis of the cluster tree of hierarchical cluster analysis (see paper V and Figure 3). Only one group out of 66 remained out of the clusters. The whole population was split into two sections of clusters ($n = 6$ and $n = 59$ respectively) already nearly at the root of the cluster-tree and, subsequently, the bigger section was divided into four clusters (see Figure 2 in

paper V). The first discriminant function was suitable for differentiating four clusters out of five whereas the last cluster differed according to the second function. The first function correlated mainly with the time spent on solving story problems of the virtual hike and the second with students' achievement (problem solving skills). It means that the time and results of solving story problems have to be taken into account in developing a support system. However, these are not the only components of discriminant functions.

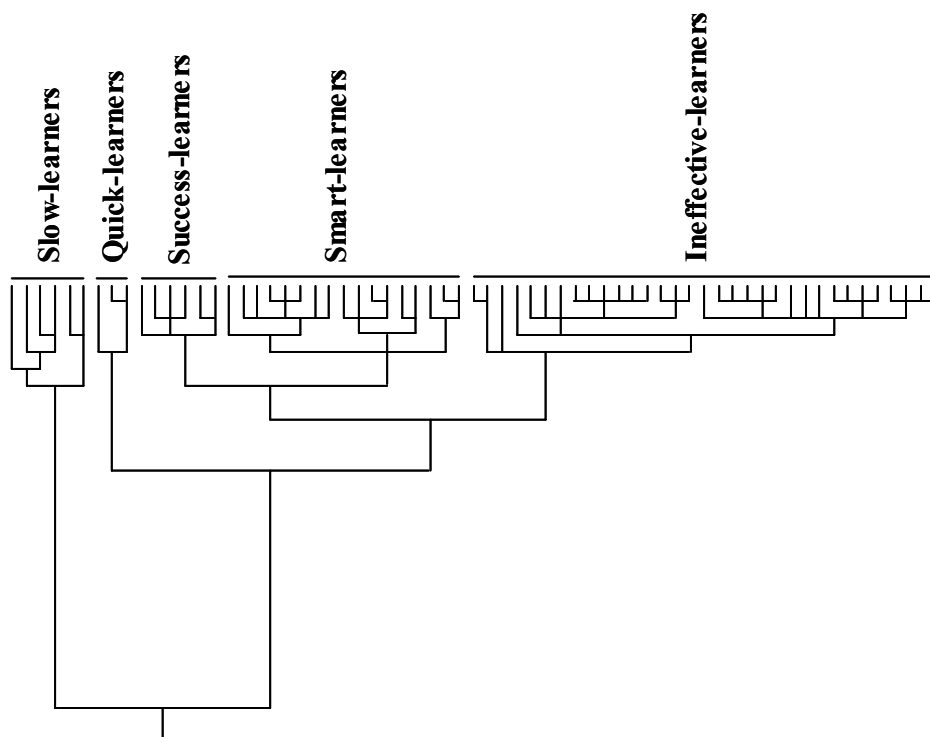


Figure 3. A cluster tree of the learning groups in the Experiment III.

In a deeper analysis the following variables played an important role in clustering: i) time used for solving problems, ii) results of the pre-test, iii) results of the post-test, iv) results of the virtual hike, v) results of the analysis of figures in the post-test, vi) results of the analysis of photos in the post-test, vii) results of the analysis of tables in the post-test, viii) results of the analysis of graphs in the pre-test, ix) number of boys in a team (see paper V).

Similar clustering was performed for the participants of the Experiment IV and, finally, the five clusters were named as follows: i) 'Slow-learners' (totally 10 out of 115 groups; 9 %), ii) 'Quick-learners' (n = 6; 5 %), iii) 'Success-learners' (n = 9; 8 %), iv) 'Smart-learners' (n = 30; 26 %), and v) 'Ineffective-

learners' (n = 60; 52 %). However, as the differences of these groups are general, and not domain- or environment-specific, it can be proposed that we have described a general diversity of the groups of learners in a web-based environment. The characteristics of these groups have to be considered in any instructional design that has similar conditions — small groups of students (aged 13-18) who learn problem solving with computers. The description of these clusters is presented in Table 2. Still, there are only the characteristics that have significant value in distinguishing different clusters (except the number of members in a team).

Table 2. Description of different clusters of small groups of students using the web-based simulation 'Hiking Across Estonia' for learning problem solving and analytical skills.

Name of the cluster (n)	Initial level of problem solving skills in the pre-test (%)	Average size of the team (n)	Average ratio of boys in a team (%)	Time spent on learning in the virtual hike (minutes per problem)	Average achievement on solving the problems of virtual hike (%)	Development in problem solving comparing the pre- and post-tests (%)
Slow-learners (n = 10)	36	3.8	51	39	67	9.8
Quick-learners (n = 6)	26	3.7	67	15	95	10.3
Success-learners (n = 9)	38	4.3	31	27	60	12.5
Smart-learners (n = 30)	37	3.9	9	18	60	11.0
Ineffective-learners (n = 60)	28	3.7	53	10	43	3.5

Our findings reveal (see Table 2) that the initial level of the students' skills does not play an important role in determining the effectiveness of learning process (variable development) rather than the strategy of learning (appears in variables time and general achievement) and even the ratio of boys. It means that the improvement in solving story problems taking place in small groups in a web-based environment is predictable after the groups of learners have solved some

particular problems. The predicted cluster can be supported during the following learning process and, therefore, the instruction for teaching problem solving skills has to contain a number of tasks. The importance of similar adaptive approach has been demonstrated in the study of Veermans et al. (2000) concerning feedback. In addition, Zhang (2000) evaluated with success a reflective support system in improving learners' skills in a discovery-learning environment. However, both of them did not apply such a cluster-based approach that has been developed in our study. Hierarchical cluster analysis combined with discriminant analysis provides us with a very powerful and statistically controllable tool for building adapted support and feedback mechanisms if a sample of preparatory study characterises all variety of learners.

4.3. Support system

Instructional support was only provided in our Experiment IV. It was designed on the basis of the results of the Experiment III and consisted of two elements: i) supportive notes before some of the learning tasks, and ii) rearranging the sequence of story problems. However, the findings concerning different clusters indicated that there was no need for any type of support in each cluster and some of these did not need guidance at all in learning problem solving in small groups using a web-based learning environment 'Hiking Across Estonia'. It means that a support system has to be in some way adaptive as proposed by many researchers (Veermans et al., 2000; Reid et al., 2003; Zhang et al., 2004). The need of adaptivity derives from the differences in learning groups embedded into certain problem solving situations. Some of these groups are able to organise their work in an effective way whereas the others need to be guided in assigning various roles in collaborative work (Cohen, 1994) or implementing specific strategies (Barnes & Todd, 1977; Forman & Gazden, 1985; Cazden, 1988; Slavin, 1990). In addition, we have to overcome the problems that can be resulted from the mixture of genders in a group (see Leaper, 1991; Strough & Berg, 2000; Strough et al., 2001).

An effective support system for the groups of learners was developed on the basis of the main characteristics found from the discriminant analysis (see paper II and Table 2) and the information about problem solving strategies of these groups (see Table 3 in paper II). One of the main reasons for failing in learning with 'Hiking Across Estonia' was the lack of situation awareness and its components, especially contextual, or task and process awareness (Sonnenwald et al., 2004). Therefore, the following interventions were performed for particular clusters (see papers II and I):

- The cluster of 'Slow-learners' had difficulties with more complex tasks. Therefore, the sequence of the tasks was rearranged — they were provided with simpler problems first. These students also spent too much time on

solving problems and, subsequently, the notes for enhancing task and process awareness were added.

- A small cluster of ‘Quick-learners’ spent little time and did not control their answers before submitting them and, obviously therefore, failed in solving the most difficult problems that based on analysing figures and tables. Thereby, the notes about the need of controlling their answers were added.
- The cluster of ‘Success-learners’ used different methods for analysing data (advanced problem solving strategy) and, due to this, had a high progress according to the comparison of the pre- and post-test. Apparently, they did not need any support.
- Another cluster of ‘Smart-learners’ demonstrated the highest development during solving the story problems of the simulation because they applied extensively all the different methods for analysing data and improved considerably in the results of the test. Therefore, they did not need any support.
- A considerably big cluster of ‘Ineffective-learners’ had major difficulties with complex tasks but they also failed in solving easier problems. On the other hand, they solved tasks too quickly and, therefore, the sequence of the tasks was rearranged. Next, these groups were provided with simpler problems first and some notes for enhancing their contextual awareness were added.

The clusters in the Experiment IV were predicted with discriminant analysis. In this case, the results of pre-test were discarded from the analysis and only used for determining groups’ improvement in problem solving skills (see paper I). However, it was interesting that the prediction power of the discriminant analysis without these data was even higher. It could be explained by the difference in the tasks of the test and virtual hike.

In conclusion, the sequence of the tasks remained unchanged in comparison with the Experiment III for three clusters out of five (‘Quick-learners’, ‘Success-learners’, and ‘Smart-learners’) whereas the others needed a modified sequence after the 4th task out of 25. Still, the sequence and position of the five complex tasks (one in each virtual ecosystem) stayed unchanged. The supportive notes were provided before solving each of the complex story problems — ‘Slow-learners’ and ‘Quick-learners’ got guidance for enhancing their task and process awareness, and ‘Ineffective-learners’ for contextual awareness (see paper II).

4.4. Factors influencing the effectiveness of problem solving

The factors that have a significant influence on the effectiveness of learning to solve story problems in small groups were determined in two stages: i) identifying the differences of clusters (on the basis of their effectiveness in problem solving) with discriminant analysis, and ii) comparing the results of each cluster in the Experiment IV with the previous, in order to evaluate the

effectiveness of the supportive notes and rearrangement of the sequence of story problems. The general discussion and conclusions about the list of important factors are presented in paper I whereas some implications of it are also described in papers V, IV, III, and II.

The discriminant functions used for selecting the factors that influence significantly collaborative problem solving in web-based learning environments were the following:

$$\text{Function 1: } C = 0.71T + 0.54\text{ProS} + 0.25\text{TabS} - 0.25\text{PreS} + 0.21\text{FigS} + 0.06\text{GraS} + 0.01G \quad (\chi^2 = 83.3, p < 0.01).$$

$$\text{Function 2: } C = -1.65\text{PreS} + 0.88\text{FigS} + 0.63G + 0.48\text{ProS} + 0.17\text{TabS} + 0.13\text{GraS} + 0.02T \quad (\chi^2 = 39.0, p < 0.01).$$

Key:

C = cluster of learners' groups;

T = time used for solving problems;

ProS = problem-solving achievement according to the first four tasks in the virtual hike;

PreS = problem-solving achievement according to the pre-test;

TabS = result of the analysis of tables in the pre-test;

FigS = result of the analysis of figures in the pre-test;

GraS = result of the analysis of graphs in the pre-test;

G = ratio of boys in a team.

Our results supported the classification of factors influencing problem solving proposed by Funke and Frensch (1995) or Jonassen (2000) who distinguished external (describing learning environment and its tasks) and internal (concerning learners) factors. Besides, the present thesis gives a broader sense to both these types in the aspects of collaborative learning and adapted support (Reid et al., 2003; Zhang et al., 2004) to learners' metacognition (Flavell, 1976) and situation awareness (Sonnenwald et al., 2004).

In our research, the most important factors that had a statistically significant influence on groups' performance in acquiring problem solving and inquiry skills were the following:

- the time spent on learning;
- the initial skills of problem solving;
- the ratio of genders in a learning group;
- the presence of support for enhancing particular type of situation awareness (task- and process or contextual);
- the graduation of problem-tasks sequenced on the basis of complexity and difficulty.

It is obvious to make an inference that time spent on learning has a strong influence on the students' performance. However, it appears in our study that the 'best duration' of learning process depends on students' cluster. It means that some groups of students can learn successfully even with a short time and

the others use too much without good results due to the absence of situation awareness or weak strategies for solving problems. The factor 'time' was selected as the variable that had the strongest correlation with the first discriminant function, which differentiated the clusters in our studies. However, the 'time' can symbolize different meanings in these functions. In the case of 'Slow-learners' it could indicate the lack of task and process awareness, while the groups of this cluster spent 39 minutes per task but had no statistically significantly better results compared with other clusters. 'Time' for 'Quick-learners' or 'Ineffective-learners' could mean a low level of contextual awareness that led to the situation where some answers to the problems were produced not on the basis of the information available in the learning environment. They did not use the resources of the 'Hiking Across Estonia' or they did not even know that there were any additional materials.

Initial knowledge and skills belonged to the second factor defining the clusters of groups in our studies. However, the differences in general problem solving performance were not remarkable (see Table 2) and, therefore, we were interested in deeper analysis of their problem solving skills. In the case of story problems, the capability to identify the key elements from the story is the crucial stage leading the whole subsequent process of problem solving (Sherrill, 1983; Novick, 1988; Blessing & Ross, 1996; Woods et al., 1997). For this reason, we evaluated various analytical skills that were needed by students for interpreting the stories of the problems and for deciding if the actual problem contributed to any known schemata (see Riley & Greeno, 1988; Chi & Bassok, 1989; Ferguson-Hessler & de Jong, 1987; de Jong & Ferguson-Hessler, 1996). In our studies, we assessed learners' skills to analyse tables, graphs, figures, and photos that were embedded into stories. It appeared that all these skills were independent from each other since all these were applied in the final discriminant functions. It also revealed that students' initial skills to analyse graphs and photos played an important role in determining the outcome in ineffective clusters of 'Slow-learners' and 'Ineffective-learners', while the level of the skills to analyse tables and figures related to distinguishing more effective groups: 'Quick-learners', 'Success-learners', and 'Smart-learners'. Therefore, it was concluded that the skills to analyse graphs and photos were lower level abilities compared with the analysis of tables and figures. The former ones were presented in the clusters 'Success-learners' and 'Smart-learners' whereas the latter were partially developed in those cases.

Thirdly, it appeared that generally the groups mainly containing girls had better achievement compared with others. It means that the groups of boys need much more guidance than the groups of girls. This finding is supported by the theories of collaborative learning that take into account the differences of genders (see Gilligan, 1982; Sheldon, 1990; Fultz & Hertzog, 1991; Leaper, 1994; Jarvinen & Nichols, 1996; Rose & Asher, 1999). Strough and Berg (2000) have demonstrated that girls use more high-affiliation strategies than boys in collaborative situations and, therefore, learn more with shorter time;

while boys, on the other hand, focus on dominance and asserting themselves (Leaper, 1991). We can agree with these theories in general but while looking into the differences of various clusters of learning groups we have noticed among the others two little groups that are exceptions to these theories: i) one cluster that contains mainly girls but is still ineffective due to the absence of situation awareness ('Slow-learners', about 9 % of groups) and, ii) another cluster with the groups of boys who are very successful with a minimal time ('Quick-learners', about 5 % of groups). It means that it is not only the matter of the gender of learners without other variables proposed in our list of significant factors, when developing an instructional design concerning a web-based collaborative learning environment for problem solving.

The fourth factor — 'the presence of appropriate support' — was evaluated comparing the results of three ineffective clusters ('Slow-learners', 'Quick-learners', and 'Ineffective-learners') in the Experiment III and Experiment IV. Two highly effective clusters ('Success-learners' and 'Smart-learners') served in this analysis as control groups. These ineffective clusters were provided with different supportive notes that were composed on the basis of the difficulties, characteristic to the analogous clusters in the Experiment III. Therefore, we can conclude that these notes for improving either contextual or task and process awareness enabled to develop learners' skills to solve story problems statistically significantly comparing without any support (see papers II and I). Even more, this support was appropriate for overcoming the initial weaknesses of these groups, as there were no statistically significant differences between these and other (effective) groups. It concludes that the adapted support is one of the essential components of collaborative computer-based environments for learning problem solving and inquiry skills.

The fifth identified factor that has a significant influence on the effectiveness in solving story problems was 'graduation of problem-tasks sequenced on the basis of complexity and difficulty'. The importance of the sequence was clarified with comparison of the results in pre- and post-test and virtual hike in the Experiment III (without rearrangement of the sequence) and Experiment IV (with rearrangement). Two ineffective clusters ('Slow-learners' and 'Ineffective-learners') that had problems with more difficult tasks in the Experiment III were under investigation for that purpose. In the Experiment IV, the sequence of the tasks was rearranged and consequently they solved simpler problems first and moved on to the more difficult ones step by step. The importance of the order of learning operations is demonstrated by Landa (1974, 1976), however, in the current study this approach was applied by groups of learners. As a result of that, these clusters demonstrated the biggest improvement of problem solving and analytical skills in the Experiment IV. Moreover, 'Ineffective-learners' became the only group where all analytical skills (skills to analyse graphs, photos, figures, and tables) increased. Therefore, it can be concluded that the design of an adapted learning process has to consider the factor 'sequence of the learning tasks'.

5. CONCLUSIONS AND IMPLICATIONS

5.1. Conclusions

On the basis of all studies related to this thesis, it is possible to make conclusions concerning four particular aspects: the evaluation of the learning environment 'Hiking Across Estonia', the types of learning-groups in collaborative web-based problem solving environment, the support system for web-based problem solving, and the factors that influence the effectiveness of learning to solve problems.

The learning environment 'Hiking Across Estonia' was developed especially for acquiring problem solving skills by small groups of learners. For evaluating that, two different pre- and post-tests were composed and students' improvement during the virtual hike was measured. It was found in all studies — Experiment I, Experiment II, Experiment III, and Experiment IV — that the application of 'Hiking Across Estonia' improved students' general outcome in solving story problems. Additionally, the Experiment III revealed that their analytical skills concerning the analysis of tables and photos improved statistically significantly. However, learners' skills to solve problems that based on analysing graphs and figures did not develop in the Experiment III. In the following analysis, the whole sample of learning groups was divided into five clusters and it appeared that the performance in different skills depended on the cluster a particular group belonged to. Next, a support system was composed for these clusters that were ineffective in learning to solve story problems, and providing these clusters with appropriate support system their progress increased statistically significantly. Finally, we can conclude that this web-based learning simulation with the support system is effective for developing learners' general problem solving skills, and their particular skills to analyse tables, photos, graphs, and figures in small groups of learners from the 6th to the 12th form.

The groups of students in the learning environment 'Hiking Across Estonia' were divided into five clusters. These were characterised in order to take into account their differences in improving the instructional design for developing problem solving skills collaboratively. Two effective clusters were identified — 'Success-learners', 'Smart-learners' — and three ineffective clusters — 'Slow-learners', 'Quick-learners', 'Ineffective-learners'. The groups of 'Slow-learners' (9 %) contained mainly girls who spent a lot of time on learning with no significantly bigger improvement compared with others. Their difficulties derived from low task- and process awareness. Subsequently, their awareness was enhanced by rearranging the sequence of story problems and providing them with supportive notes. 'Quick-learners' was a small cluster (5 %) of mainly boys that learned very quickly but due to hurrying they did not develop in analysing more complicated information, for example figures and tables. Therefore, they needed supportive notes concerning the most complex problems

to pay more attention to the deeper structure of these problems or, in other words, for improving their task- and process awareness. 'Ineffective-learners' indicated a cluster that covered more than a half of all the groups of learners (52 %). They demonstrated the lowest results in solving problems of the virtual hike and pre- and post-test. Therefore, they were provided with simpler problems first and supportive notes before more difficult problems. The supportive notes contained guidance for developing learners' contextual awareness because they solved problems on an average too quickly (within 11 minutes) without realising that all additional information was available in the different materials of the learning environment 'Hiking Across Estonia'.

The support system for three ineffective clusters was designed according to the results of hierarchical cluster analysis combined with discriminant analysis. It can be regarded as a very powerful approach, since all ineffective clusters improved in applying appropriate support system so much that in the post-test their problem solving skills did not differ statistically significantly from those of effective clusters. The system implied two activities: rearranging story problems of the virtual hike, and providing learners with supportive notes for enhancing their situation awareness. Its effectiveness was clarified with comparison of two studies where the same clusters used 'Hiking Across Estonia' with and without support system respectively. The results demonstrated statistically significant increase towards students' bigger improvement in problem solving outcomes and skills to analyse graphs, figures, and tables.

On the basis of different studies, a list of factors that had a significant influence on the collaborative web-based problem solving in a web-based learning environment was compiled. These factors were the following: i) the time spent on learning, ii) the initial skills of problem solving, iii) the ratio of genders in a learning group, iv) the presence of supportive notes for enhancing situation awareness, v) the graduation of problem-tasks sequenced on the basis of complexity and difficulty. The factor 'time' could indicate a low level of task and process or contextual awareness. The absence of task and process awareness led groups to time wasting since they did not know how to use available information. The lack of contextual awareness caused hurrying since the students did not even know that there were appropriate materials in the learning environment. Lower level of initial problem solving skills resulted in a slight improvement of them without the support system due to the difficulties in identifying the key elements from the story. Groups containing mainly girls had better achievements compared with boys who seemed to need much more guidance. Supportive notes had to be either for enhancing groups' contextual or task and process awareness according to the characteristics of particular clusters. And finally, the appropriate sequence of story problems appeared to be important for some clusters of learning groups. There were five problem-tasks in each ecosystem out of five. At first, the difficulty level of these ecosystems was balanced; however, in the Experiment IV for two ineffective clusters of learners some of the tasks were transferred from one ecosystem to another. Due

to this rearrangement, they solved simpler problems first and moved on to the more difficult ones step by step. As a result of the new sequence they improved in general problem solving skills and all analytical skills statistically significantly more than in the Experiment III.

On the basis of the findings in all four studies, we can conclude that the web-based learning environment 'Hiking Across Estonia' is applicable for acquiring effectively problem solving and inquiry skills by small groups of students who are learning without the guidance of a teacher. However, it has to be pointed out that the significant improvement in problem solving only reveals in all groups when appropriate support is provided for groups with certain characteristics, which distinguish the clusters of learners.

Still, there are some limitations in using the findings of the present research in new learning environments. Firstly, there was no random sample in our studies. The conclusions have been made on the basis of all-Estonian competitions where a limited number of voluntary students participated. It can be hypothesised that these were more motivated learners since only six groups were allowed to participate from each school.

The second limitation could be derived from the design principles of the learning environment and its support system. In the present case, the first four simple problems of the virtual hike were used as the 'diagnostic tasks' for clustering because these all embedded the particular types of analysis needed in solving other story problems. However, a number of the 'diagnostic tasks' may vary depending on their diagnostic value established, for example, by discriminant analyses.

5.2. Implications

Three groups of implications can be drawn from the findings of current research. These should be addressed to teachers, instructional designers, and researchers as well.

In organising the learning process, all teachers and especially the science teachers have to take the following into account:

- i) The difficulty level of story problems depends on the type of analysis needed for solving them. Stories that embed graphs and photos in addition to texts are easier than those that contain figures and tables as well.
- ii) The story problems have to be presented to learners in an appropriate sequence. It could lead to lower motivation and outcome if there are some too complex tasks at the beginning of learning process.
- iii) Solving complex problems is a complicated process and this complexity is often not realised by learners. Providing them with a support for enhancing their situation awareness is an important factor that helps learners to solve story problems effectively.

Although, the instructional designers have to consider the same implications as teachers, there are some additional guidelines specifically for them:

- i) The effectiveness of a web-based learning environment for developing learners' skills to solve problems depends on the appropriate support. Therefore, the design of the support system has to be a key stage in composing any instructional computer-based system.
- ii) The support system for students has to be adapted according to their characteristics since the clusters of learners are very different in their strategies of learning. Therefore, it is necessary to specify the variety of learners at first and, next, to design a support system according to their characteristics.
- iii) The methodology of combining hierarchical cluster analysis with discriminant analysis for developing a support system appeared to be very effective and, therefore, we recommend applying that for instructional design process. According to this methodology, the following seven steps have to be implemented:
 - composing a learning environment;
 - applying it with a pilot group;
 - clustering the learners according to their strategies and outcomes of learning and personal information using hierarchical cluster analysis;
 - determining by discriminant analysis the differentiating factors of the clusters found;
 - designing an initial support system according to these factors;
 - running a second study where the clusters of learners are predicted with discriminant analysis;
 - evaluating the effectiveness of the support system with comparing the results of different clusters in the pilot and second study.

And finally, we can propose some ideas for further research:

- i) There were two interesting clusters of learning groups in the present studies: 'Slow-learners' and 'Quick-learners'. However, the number of groups in these clusters was too small to make broader generalisations. Therefore, a deeper qualitative analysis is needed in further studies.
- ii) In the present case, the support system included rearranging the sequence of the tasks and supportive notes. As these were applied simultaneously, the individual effect of the notes and sequence has to be clarified with a different design of the study.
- iii) As the present research was based on the participants of all-Estonian competitions, it was not possible to analyse groups' strategies of problem solving qualitatively. The qualitative approach could add some new important aspects for deeper understanding of the strategies of learning problem solving.
- iv) The present method of creating support system has been controlled concerning only one learning environment. The applicability of this method in analogous learning environments has to be verified in further studies.

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SUMMARY IN ESTONIAN

Probleemide lahendamine veebipõhises õpikeskkonnas

Käesoleva töö esmaseks eesmärgiks oli veebipõhise õpikeskkonna väljaarendamine, mis võimaldab efektiivselt arendada õpilaste probleemilahendamisioskusi õppimisel väikestes gruppides õpetaja abita. Selleks koostati situatsiooniline õpisimulatsioon 'Tiigriretk Eestimaal' (<http://bio.edu.ee/matk/>), mille abil saab jälgida kogu õpiprotsessi ja salvestada selle kohta vajalikku informatsiooni. Keskkond sisaldas algselt 35 probleemülesannet ökoloogia ja keskkonnaõpetuse teemadel. Need esitati õpilasarühmadele simuleeritud matkal läbi viie ökosüsteemi: palumets, salumets, aruniit, lamminiit ja raba. Õpikeskkond sisaldas ülesannete lahendamiseks ka kõiki vajalikke virtuaalseid töövahendeid ning infomaterjale. Selles olid programmeeritud lisavõimalused esitada õpilastele spetsiifilist infot enne iga ülesande lahendamist ning anda tagasisidet pärast vastuste hindamist. Doktoritöö esimene uurimisküsimus oli seotud õpikeskkonna evalveerimisega: milline on õpikeskkonna 'Tiigriretk Eestimaal' rakendamise tulemuslikkus väikestes gruppides õppivate 6.–12. klassi õpilaste probleemilahendamisoskuste arendamisel?

Õpikeskkonna kasutamise tulemuslikkust hinnati üldise probleemilahendamisoskuse ja analüüsi oskuste kaudu. Esialgsed uuringud näitasid, et õpikeskkond arendab statistiliselt oluliselt õpilaste üldisi probleemilahendamisioskusi, kuid nende areng on õpilasgrupiti väga erinev. Analüüsi oskuste hindamisel ilmnis oluline areng vaid tabelite ja fotode osas ning graafikute ja jooniste analüüsi oskus ei suurenenud. See tingis vajaduse selgitada välja, kuidas on võimalik õpilasgruppe kategoriseerida, et seejärel luua igat tüüpi rühmale sobiv toetussüsteem probleemilahendamisoskuste efektiivseks omandamiseks. Sellest lähtus ka käesoleva töö teine uurimisküsimus: milliseid õpilasgruppide tüüpe on võimalik eristada veebipõhises õpikeskkonnas probleemide lahendamise õppimisel ning kuidas iseloomustada neid tüüpe?

Hierarhilise klasteranalüüsi abil selgus, et õpilasgrupid jaotuvad viide tüüpi, mis on eristatavad probleemide lahendamisele kulutatava aja, probleemilahendamisoskuste ja rühmade soolise koosseisu alusel. Kaks tüüpi koosnesid probleemilahendamise oskuste omandamisel tulemuslikest ja kolm mitte-tulemuslikest gruppidest. Järgnevalt analüüsiti iga mitte-tulemusliku tüübi probleemilahendamise strateegiaid ja leiti, millist laadi toetust need vajavad. Kolmas uurimisküsimus oligi seotud toetussüsteemi loomisega: millised toetussüsteemi komponendid on olulised eri tüüpi õpilasgruppidele, et tõsta nende tulemuslikkust probleemilahendamisoskuste omandamisel?

Õpikeskkonna toetussüsteemi disainimisel kasutati probleemülesannete ümberreastamist ning situatsiooniteadlikkust toetavate juhiste lisamist. Ühe uuringu põhjal koostati erinevatele gruppide tüüpidele teoreetiliselt sobiv toetussüsteem. Sellele järgnev eksperiment võimaldas hinnata toetussüsteemi

tulemuslikkust. Selleks leiti diskriminantanalüüsi abil, millisesse tüüpi iga grupp võiks kuuluda ja pakuti tüübile vastavat toetust. Kui algselt olid viie ökosüsteemi keerukused sarnased, siis teatud tüüpi gruppidele osutus vajalikuks muuta ülesannete järjekorda nii, et nende esitus toimuks järk-järgult lihtsamalt keerulisemale. Toetusjuhiseid tuli anda sõltuvalt õpilaste algsetest probleemilahendamisoskustest kas õpikeskkonnas olevate materjalide olemasolule viitamiseks või nende kasutamise selgitamiseks.

Töö tulemusena sai õpikeskkonna ja selle toetussüsteemi hindamisega seonduvalt välja tuua olulised tegurid, mis mõjutavad õpilasgruppide tulemuslikkust veebipõhises keskkonnas ühiselt probleemilahendamisoskusi omandades: i) õppimiseks kulutatud aeg, ii) probleemilahendamisoskuste algtaase, iii) eri soost õpilaste osakaal grupis, iv) situatsiooniteadlikkuse erinevaid tüüpe toetavate juhiste olemasolu, v) probleemülesannete järjekord, mis tuleneb nende kompleksisusest ja keerukusest. Loetletud tegurite arvestamisel vastavalt iga õpilasgrupi tüübile ilmnes, et varem probleemilahendamisoskusi mitte-tulemuslikult omandanud tüüpidesse kuulunud gruppide areng oli toetussüsteemi rakendamisel statistiliselt oluline ja samaväärne juba eelnevalt tulemuslikesse tüüpidesse kuuluvate gruppide arenguga. Seega on käesolev uurimistöö oma eesmärgid täitnud.

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I would also like to express my gratitude to the students and teachers who participated in these studies.

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PUBLICATIONS

DEVELOPING STUDENTS' PROBLEM SOLVING SKILLS BY LEARNING SIMULATION "HIKING ACROSS ESTONIA"

Margus Pedaste, Tago Sarapuu

ABSTRACT

A unique web-based learning environment "Hiking Across Estonia" ([http://bio.edu.ee/ tour/](http://bio.edu.ee/tour/)) comprising two modules – one for students and another for developers and researchers – has been composed. Students have to solve 30 environmental problem-solving tasks in five virtual ecosystems with the help of additional information and virtual tools that can be opened in the same window. The answers of participants are saved in the database of the server for analysing students' performance in solving the tasks. An all over Estonian competition between teams consisting of three to five students ($n = 462$) of basic and high school was organized in the spring of 2002. The ANCOVA analysis of the participants' answers in the pre- and post-test demonstrated the improvement of students' problem-solving skills statistically significantly ($F = 195.8$; $p < 0.001$). This finding was strongly influenced by their achievements in the pre-test ($F = 9.2$; $p = 0.003$) – the participants with initial lower problem-solving skills developed considerably more. It was also verified that students' skills to analyse texts ($F = 16.9$; $p = 0.015$), graphs ($F = 71.2$; $p < 0.001$) and figures ($F = 13.2$; $p = 0.030$) improved as a result of the application of the simulation. The analysis of the server database supported the fact that the students' ability to solve the problems developed significantly – according to the Spearman rank order correlation the score per task increased during the usage of the programme. The achievements of basic school students improved more ($\rho = 0.393$; $p = 0.016$) than these of high school students ($\rho = 0.255$; $p = 0.087$).

KEYWORDS

Problem solving, web-based simulation, analysis of graphs, figures, and texts.

INTRODUCTION

By simulating real objects, phenomena and experiments, computer-assisted learning can be practised to raise the quality to a higher cognitive level and to substitute for shortage of time and equipment (Roberts et al., 1983; Lazarowitz & Tamir, 1994). Exploratory learning environments, including simulations, give students the opportunity to control their understanding and find out misconceptions. They can manipulate different models of science and also information sources, both in written and illustrated form and construct new system of knowledge based on the old one (Brooks, 1990). Students draw direct connections between tasks in learning environment and real world by solving everyday problems (Needels & Knapp, 1994). In a situational simulation the participant is an integral part of the programme and because of this he or she can transfer more knowledge and understanding to practice in real world (Alessi & Trollip, 1985).

A computer-supported learning environment is not just a loose aggregate of tools, but an integrated system. The tools are mutually related and adjusted, so that for instance the result of an investigation can be processed by an analysis programme and subsequently sent forward to a distributed database, which stores experimental results attained at laboratories across the virtual world (de Jong & Rip, 1996). Carroll and Mack (1984) argued that exploration plays a major role in learning an application. As there is often a difference between the learning goals of the users and the externally imposed

structure, users tend to rely strongly on self-directed activities. Experimental studies indicate that exploratory learning is often more efficient than externally directed learning activities (Kamouri et al., 1986; Frese et al., 1988). According to Oppermann and Simm (1994) users learn to use a learning environment mainly by trial and error. Therefore, we can conclude that the design of an exploratory simulation must support the self-directed learning.

Harper (1997) used environmental exploratory simulations “Investigating Lake Illuka” and “Exploring the Nardoo” and demonstrated the improvement of students’ problem solving skills. In these simulations students had the access to real databases about natural ecosystems but they had no guidance for solving problems. Corderoy (1993) also showed the increase of the higher order cognitive skills, which are important for solving problems. He demonstrated that the skills to analyse, synthesize and evaluate different kind of information mainly develop in due to applying of exploratory learning programmes. Gimblett (2001) described an ongoing research work into the development of a simulation system for analysing the complex human-environment interactions in dynamic settings. In his work it was argued if learning how to solve complex problems without self-directed exploration was possible at all.

The present research concentrated on evaluating the increase of students’ problem-solving skills and their ability to analyse different types of information. This study was based on a situational web-based learning simulation “Hiking Across Estonia” (<http://bio.edu.ee/tour/>), which has been worked out in the Science Didactics Department at the University of Tartu (Sarapuu & Pedaste, 2001).

LEARNING ENVIRONMENT

The learning environment was created taking into consideration theoretical aspects published in scientific literature, analogous learning environments, the curricula and other teaching materials of Estonia and several developed countries. The web-based situational learning simulation “Hiking Across Estonia” (<http://bio.edu.ee/tour/>) is unique as to its content, extent and technical solutions both in Estonia and abroad. The programme comprises learning environment with tasks and supplementary materials and administrative pages for developers and researchers of the simulation. Administrative pages give access to all information saved in MySQL database in server – learners’ names, sex, age, school, their answers to the educational tasks and points gained during the virtual hike.

The technical organization of the simulation is presented on figure 1. It can be divided between three computers: server, users’ and administrators’ computers. Both users and administrators ask for information from server, programmes in server verify if it is allowed to give them this kind of information, ask additional data from MySQL database and generate HTML-pages.

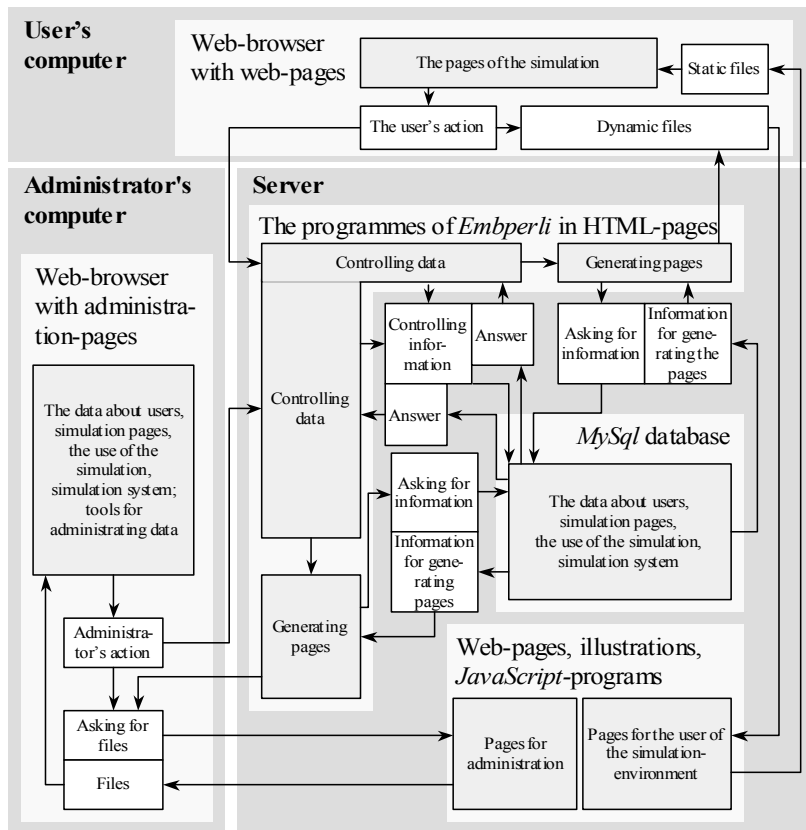


Figure 1. The principal organization of the interaction between three computers

The hike in the learning environment can be started after registration when learners are provided with username and password (figure 2). The pages of survey, participants, organizers, links and the map of the hike are available without registration. All the background information about the simulation and also the results of different virtual hikes organized in the learning environment are accessible through these pages. Learners get acquainted with five ecosystems during the virtual hike: heath forest, meadow, grove, waterside meadow and bog. Each ecosystem has six control points and six ecological or environmental tasks. The problems of the virtual hike occur in a certain order according to their structure. The informative pages provide hikers with all the information needed for solving problems. There are links to the pages of articles in the upper menu of the simulation programme and links on the main page to the informative windows about different species. An additional problem embedded in the learning environment is eating, which must be sufficient and multifarious. Students can take some food from virtual home and various ecosystems and bring it with them through the hike and eat when needed. In order to locate themselves students can open a realistic map in the upper menu. Simulation ends on the page where learners can analyse their results and compare them with these of other participants of the competition.

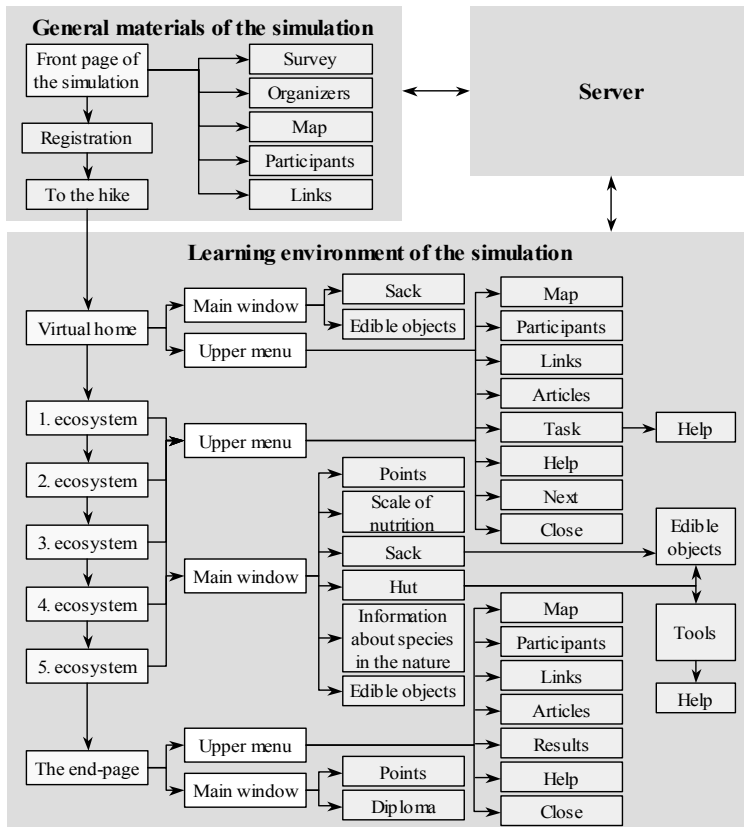


Figure 2. The structure of the learning environment

Students have to solve one problem in each control point of the virtual hike. They open the task and identify the problem (figure 3). During the analysis of possible answers they represent the problem and select a strategy. There is more than one successful algorithm for each task and in this part of problem solving it is very important that students are in small groups because then a shared mental model can be formed. Implementing the strategy enhances the usage of virtual tools (microscope, magnifier, ruler, and tools for analysis of air, soil, and water and for estimation the pH of environment). For answering students have to mark radio-buttons, check boxes and scroll-bars or draw lines and arrows between texts and pictures. The pictures in tasks can be graphs, figures and photos. Students receive feedback about their performance after they have solved a task and their success can be seen as their score. This enables to organise competitions between teams. Hikers can see their achievements and compare this with others on the map and on the page of the participants. The last one also gives information about the team-members' sex, age, schools and grades.

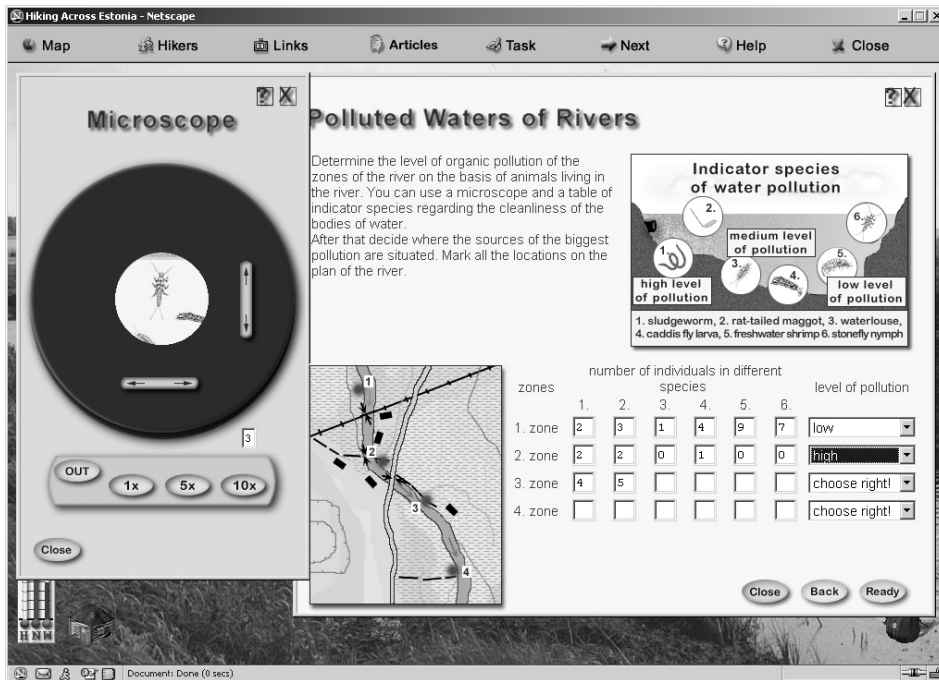


Figure 3. Educational task and virtual microscope

All the factual information needed for solving the problem can be opened in the background photo (figure 4). The last one presents the world where learners hike. Each photo of the real world is supplemented with 7 to 42 photos and so hikers can also see the things that they do not usually see in real nature: rare species, anxious animals, mushrooms growing in a specified season. 193 plants, animals and mushrooms are introduced in the learning environment and, therefore, the simulation is more effective than a real hike. Furthermore, students get a lot of data about different species. The additional information is available on the page of articles attached to the simulation or can be found through the page of links. There are 30 one-page illustrated articles about environmental and ecological issues and search tool for finding information by keywords. Students can bring food from one place to other with a virtual sack. So they can overcome the lack of different types of edible objects in some ecosystems. The programme defines the capacity of the sack and students have to consider, which food must be taken from home or nature and which not. If a virtual hiker has eaten too little food or only one type of food or something poisonous, he or she will lose points.

The additional features of the learning environment allow defining some persons as teachers. They get the possibility of constructing new virtual hikes containing problem-solving tasks according to their own objectives in a particular lesson at school. Besides, they are provided with tools for collecting the answers of their students and so they can analyse the effectiveness of the learning process.

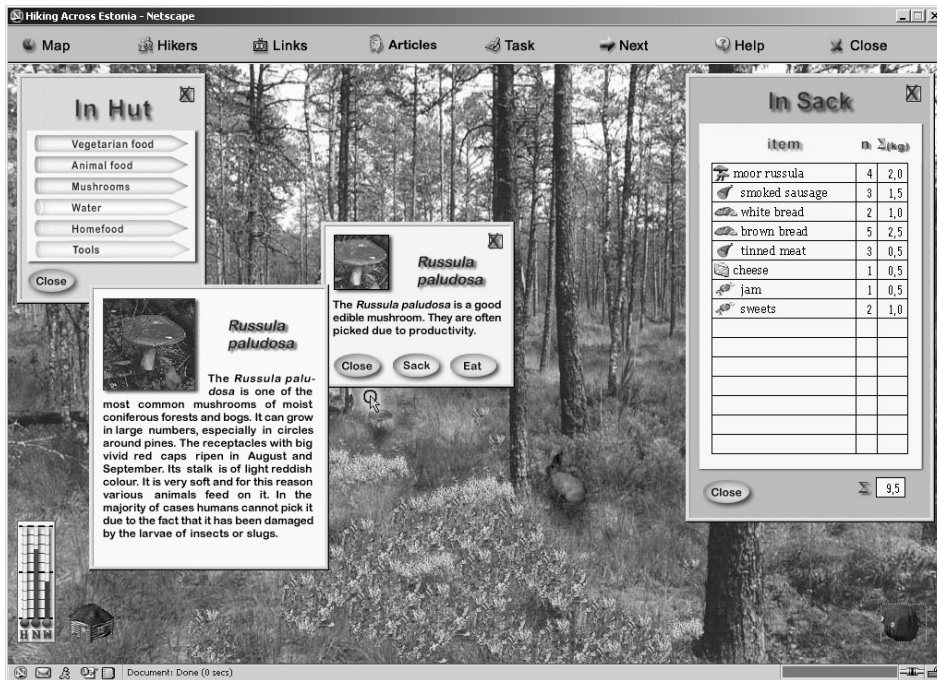


Figure 4. Bog with opened supplementary materials

METHOD

A pilot study with 24 students was conducted in order to carry out a formative evaluation of the simulation programme and to investigate the outcome of its application. 12 volunteer students of the 8th (aged 14–15) and 12 students of the 11th grade (aged 17–18) formed 6 hiking teams (consisting of four students) and filled out an electronic pre-test consisting of seven environmental and ecological problem-solving tasks. The groups of students used the simulation and marked down all snags and errors in the learning environment. After each educational task they filled out a questionnaire, to provide feedback information about the difficulty of the task and to determine the level they had understood all the texts, graphs, figures, tables, schemas, and virtual tools used in solving the problem. All the groups of students filled out a post-test after finishing the simulation. It consisted of similar questions as the pre-test. The answers in pre- and post-test were analysed in order to evaluate the applicability of the programme for developing students' problem-solving skills.

Subsequently, 111 teams with 462 students participating in all-Estonian competition organized by the Science Didactics Department completed the virtual hike. It was determined that only three groups from both basic and high school could represent each school. The intended team size was from three to five people. The distribution of groups by grade, mother tongue, and the number of members is presented on figure 5. The majority of groups were from the 7th and 8th grade, spoke Estonian, and had five members. Although the entire learning environment was in Estonian, there were 32 hiking

teams whose mother tongue was Russian. This large number of Russians gives us the opportunity to draw some conclusions about Russian community in comparison with Estonians.

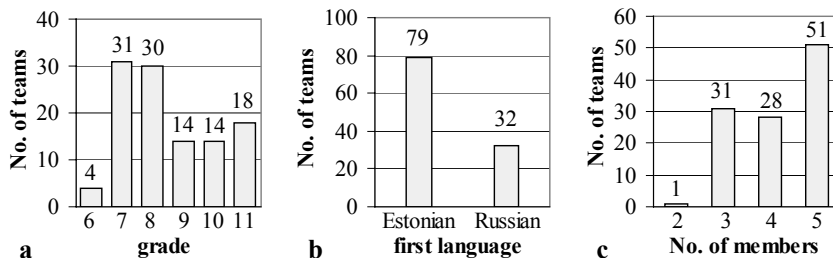


Figure 5. The distribution of finished hiking teams by grade (a), first language (b) and the number of members (c)

All the teams filled out electronic pre- and post-tests, which were similar to the tests in pilot study. The analysis of the tests and the log-files enabled us to evaluate students' progress towards problem solving. A multivariate analysis of covariance (ANCOVA) (see Cohen et al., 2000; Mertens, 1997) was performed using SPSS software. Students' grade, mother tongue, the number of group members, and their achievements in the pre-test, were analysed as covariates. A Spearman rank order correlation (see Cohen et al., 2000; Mertens, 1997) was calculated for evaluating the development of students' problem-solving skills during the simulation.

RESULTS AND DISCUSSION

The pilot study demonstrated that the simulation “Hiking Across Estonia” is applicable for developing both basic school and high schools students' problem solving skills. Groups from the 8th grade achieved 49% and teams from the 11th grade got 58% from points on average. Only 4 tasks out of 30 were evaluated by three teams as very difficult ones and only one problem was considered to be too simple. The results of all the teams were better in the post-tests.

Participants of the pilot study understood clearly all the texts, graphs, figures, tables, and schemas of the learning environment and found necessary information for solving the problems. Some difficulties were found in using virtual calculator whereas handling other tools was understandable. The help pages of the simulation were useful for solving any technical problems.

The development of problem solving skills was under investigation in the main study. A statistically significant general increase of students' problem solving skills was detected in comparison with pre- and post-test by the ANCOVA analysis ($F = 39.3$; $p < 0,001$) (table 1). This result was strongly influenced by the students' initial skills demonstrated in the pre-test ($F = 71.2$; $p < 0.001$) – the hikers with a lower score performed considerably better.

Table 1. The results of the ANCOVA analysis of the main study.

Dependent variable	SS	Df	MS	F	Sig.
problem solving	391.5	2	195.8	39.3	<0.001
analysis of texts	16.9	2	8.4	4.3	0.015
analysis of graphs	559.8	2	279.9	71.2	<0.001
analysis of figures	13.2	1	13.2	4.8	0.030

The development of problem solving skills also depended on students' nationality. Estonians advanced more than Russians (23% and 14% respectively). Although this finding was only marginally significant ($F = 2.7$; $p = 0.077$) it is interesting because it demonstrates that for developing higher order thinking skills complexly all learning materials (including background information) must be fully understandable for learners. Students who speak Russian as their mother tongue have some difficulties in synthesizing information from different sources in Estonian.

The analysis of log files supported the fact that the students' ability to solve ecological and environmental problems developed significantly by using the "Hiking Across Estonia". According to the Spearman rank order correlation the score per task increased during the usage of the simulation programme ($\rho = 0.337$; $p = 0.034$). The achievements of basic school students improved more ($\rho = 0.393$; $p = 0.016$) than these of high school students ($\rho = 0.255$; $p = 0.087$). The correlation coefficients are not very high because the difficulty of the problem solving tasks was not at the same level in all parts of the simulation (figure 6). The results in the second ecosystem were much better than in others. In other parts of the virtual hike was the difficulty level of tasks did not differ much and the students' results increased linearly. It is remarkable that there were no statistically significant differences between the problem solving skills of basic school and high schools students. It demonstrates that students do not learn how to solve problems at Estonian schools but during the five-week long competition with "Hiking Across Estonia" they attained a higher level in this field.

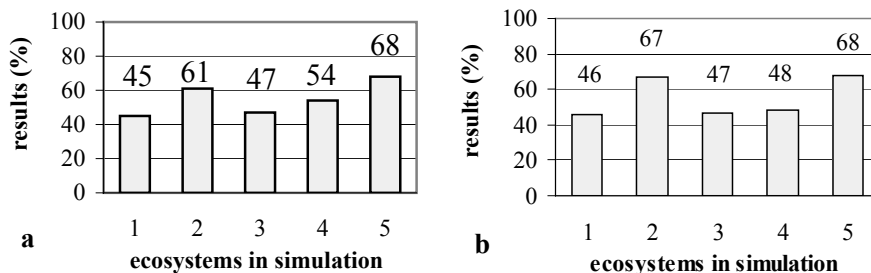


Figure 6. The results of basic school (a) and high schools (b) students on the simulation.

Students' ability to analyse different types of information was evaluated by the ANCOVA (table 1). The greatest progress occurred in reading graphs ($F = 71.2$; $p < 0.001$). It could be explained by the content of Estonian curriculum, where the development of students' ability to analyse graphs is not embedded. Students only learn how to draw graphs of different mathematical functions but do not collect information presented in the form of graphs. The improvement of this skill depended on the students' achievement of solving similar problems in the pre-test ($F = 140.5$; $p < 0.001$), their grade ($F = 6.2$, $p < 0.001$), nationality ($F = 16.9$; $p < 0.001$), and the number of group members ($F = 8.0$; $p < 0.001$). As predicted, the students with a lower level of ability to analyse graphs improved more, but other findings were more interesting. The skills of the 11th grade students increased most but the learners from the 7th and 8th grade did not show any statistically significant changes in the post-test (figure 7). Russian students improved more than Estonians because their initial skills were lower and the analysis of graphs is very little combined with understanding Estonian. As far as the size of the groups is concerned, only three-member-groups showed significant progress. The groups that had the maximum score in analysing graphs in pre-test were not included into the analysis since their progress could not be measured with our instrument. Thus, we can conclude that the skills to analyse graphs improved, especially three-member-groups of Russian students from high school.

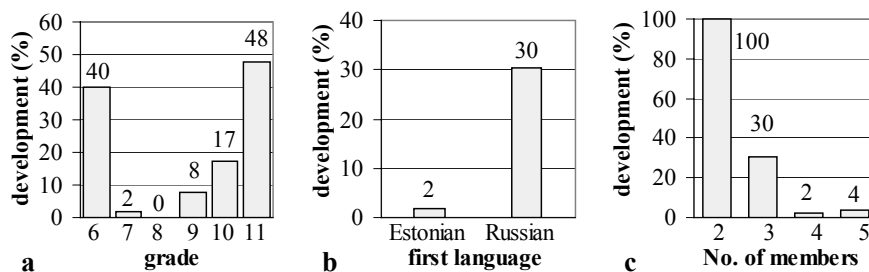


Figure 7. The development of skills to analyse graphs according to students' grade (a), first language (b) and the number of group members (c).

It was demonstrated on the basis of the ANCOVA that students' ability to analyse texts also increased as a result of the application of the simulation (table 1). The level of development depended on all the measured covariates: students' achievement according to the pre-test ($F = 20.3$; $p < 0.001$), grade ($F = 6.0$; $p < 0.001$), first language ($F = 13.9$; $p < 0.001$), and the number of group members ($F = 8.2$; $p < 0.001$). The groups with lower score in the pre-test and Russian groups with three or five members from the 9th and 10th grade improved more. The most interesting fact was that Russian students developed in reading texts in Estonian much more than Estonians. It demonstrates the power of "Hiking Across Estonia" in integrating ecological and environmental problem solving and language learning.

The ANCOVA analysis also indicated the increase of skills to analyse figures (table 1). It was interesting that the improvement in this field did not depend on students' answers

to similar questions in the pre-test ($F = 2.1$; $p = 0.132$). The development of the ability to analyse figures was generally very large (70%), but it did not correlate with any co-variables. At the same time students got the lowest scores in the tasks where they had to analyse figures. According to this the analysis of figures seems to be very difficult and needs more research in future.

CONCLUSION

Many authors have shown that exploratory learning environments are effective computer programmes for developing students' problem solving skills (Harper, 1997; Corderoy et al., 1993; Gimblett et al. 2001). We have proved with piloting that the usage of the web-based simulation "Hiking Across Estonia" is applicable for developing students' ability to solve ecological and environmental problems both in basic school and high school. This finding was confirmed in the main study.

It is another question how the use of learning environment will develop different students. Some authors (Huppert et al., 1998) have demonstrated that it depends on gender but we did not expect any statistically significant differences in this field. In our case the students who had lower problem solving skills before the usage of the simulation programme improved more. We also saw the same paradigm by detecting the change of students' skill to analyse texts and graphs. Otherwise was it in the development of the skill to analyse figures. A very significant progress in analysing figures was estimated, however it did not depend on students' grade, nationality and the number of group members.

It was interesting, that general problem solving skills mainly developed by students who spoke Estonian as their first language whereas Russians advanced more in analysing graphs and texts. The explanation of the situation could be that reading graphs is very little depending on understanding Estonian, which is a presumption of solving complex problems. The skills to analyse texts could develop more by Russians, because Estonian is not their mother tongue.

Our research based on a virtual hike consisting of 30 problem solving tasks in certain order. Each problem has a little different algorithm of solution. The learning environment "Hiking Across Estonia" also enables organizing the tasks to other virtual hikes containing one or other type of problems in different order. We can also add a pre-and post-test to the hike and additional questionnaires to specific tasks. So we can analyse the strategies of solving several types of problems and determine students' development in problem solving or inquiry skills including the ability to analyse and present information in the forms of texts, tables, graphs and figures. This study will be carried out in 2003.

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Scientific work

In 1998, I started working in the research group of educational technology in evaluating the effectiveness of web-based learning environments. The research has been concentrated on studying the factors influencing problem solving and inquiry learning in web-based environments. In the ongoing work, I have focused on the supporting aspects of computer-based inquiry learning through enhancing learners' situation awareness.

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Teadustegevus

Alates 1998. a. olen osalenud haridustehnoloogia uurimisgrupis veebipõhiste õpikeskkondade rakendamise tulemuslikkuse hindamises. Teadustegevus on keskendunud probleemide lahendamist ja uurimuslikku õpet mõjutavate tegurite uurimisele veebipõhistes õpikeskkondades. Käesoleval aja uuringud on keskendunud veebipõhises keskkonnas õpilaste situatsiooniteadlikkust arendavate toetusüsteemide mõju selgitamisele.