# 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/) 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. This finding was strongly influenced by their achievements in the pre-test – the participants with initial lower problem-solving skills developed considerably more. It was also verified that students' skills to analyse texts, graphs and figures 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 than these of high school students.

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

## INDRODUCTION

By simulating real objects, phenomena and experiments, computer-assisted learning can be practised to raise the quality of learning 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 questioned 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.

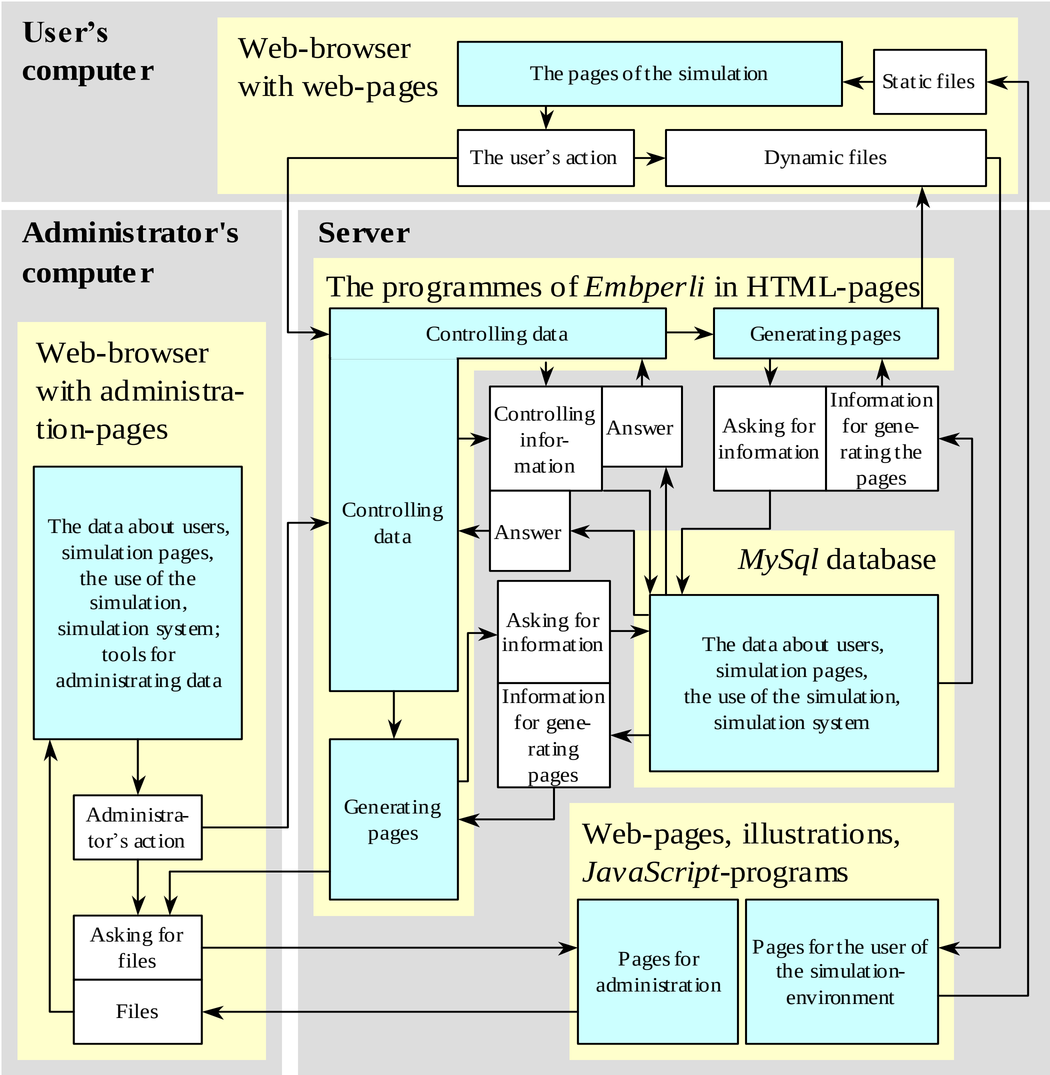


Figure 1. The principal organization of the interaction between three computers

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.

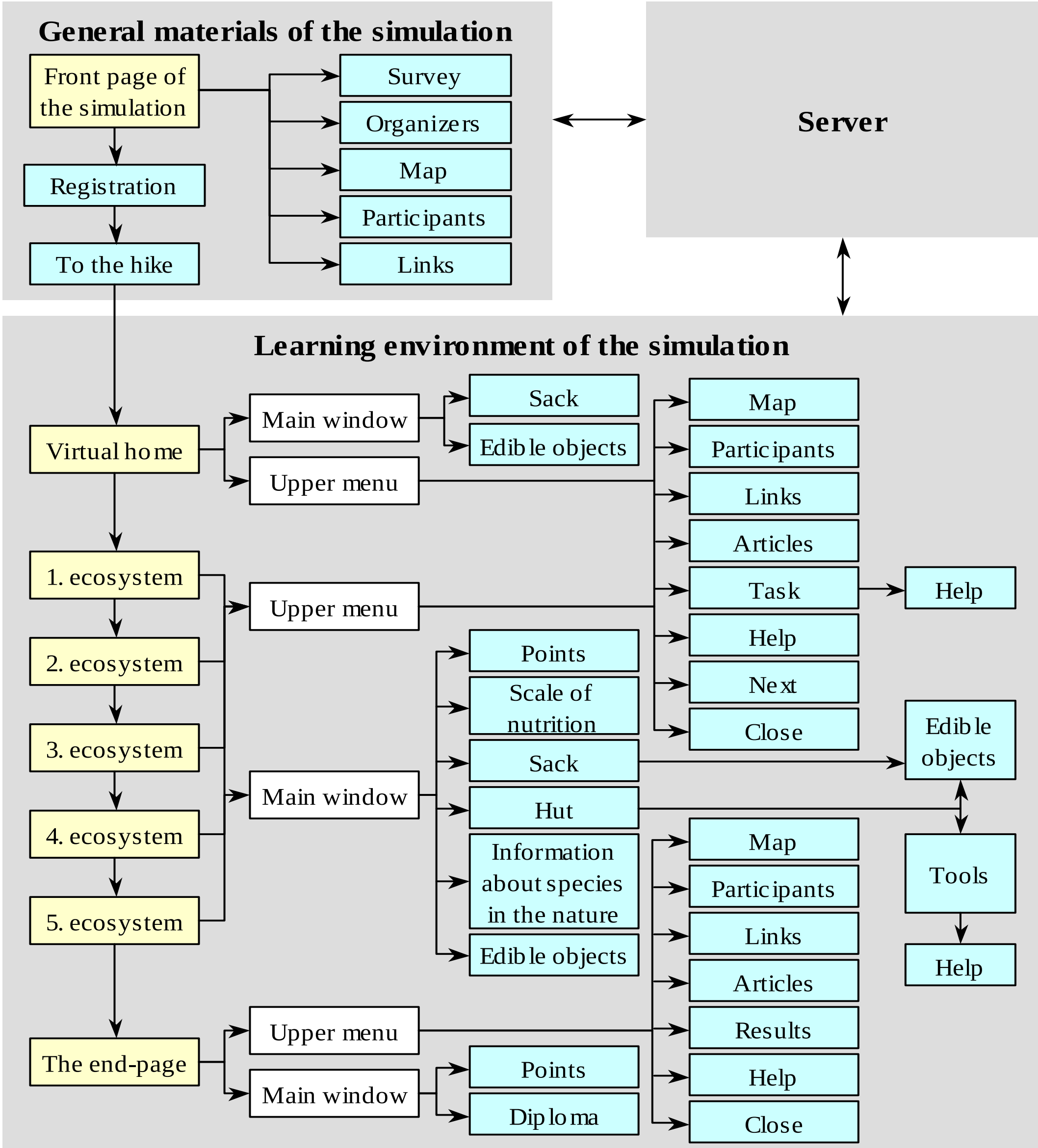


Figure 2. The structure of the learning environment

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.

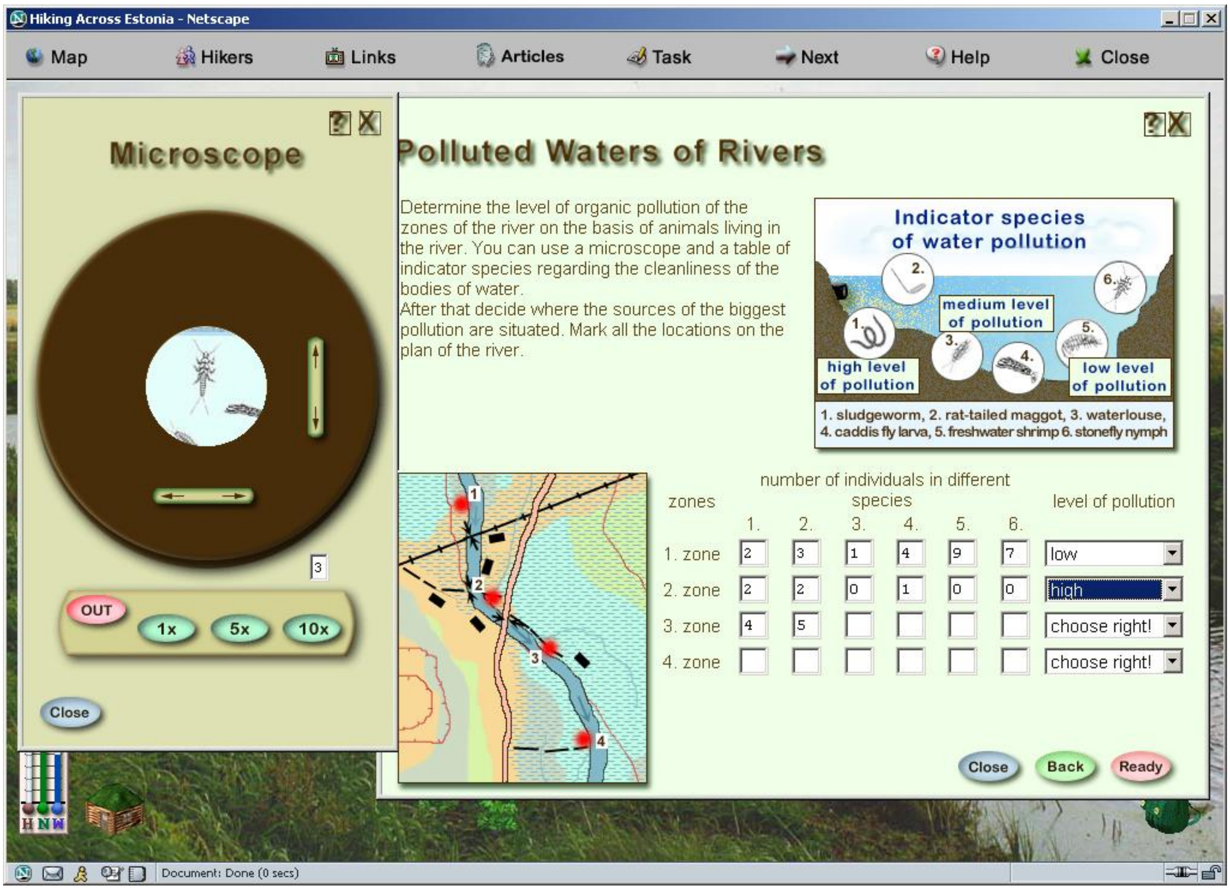


Figure 3. Educational task and virtual microscope

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 by 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.

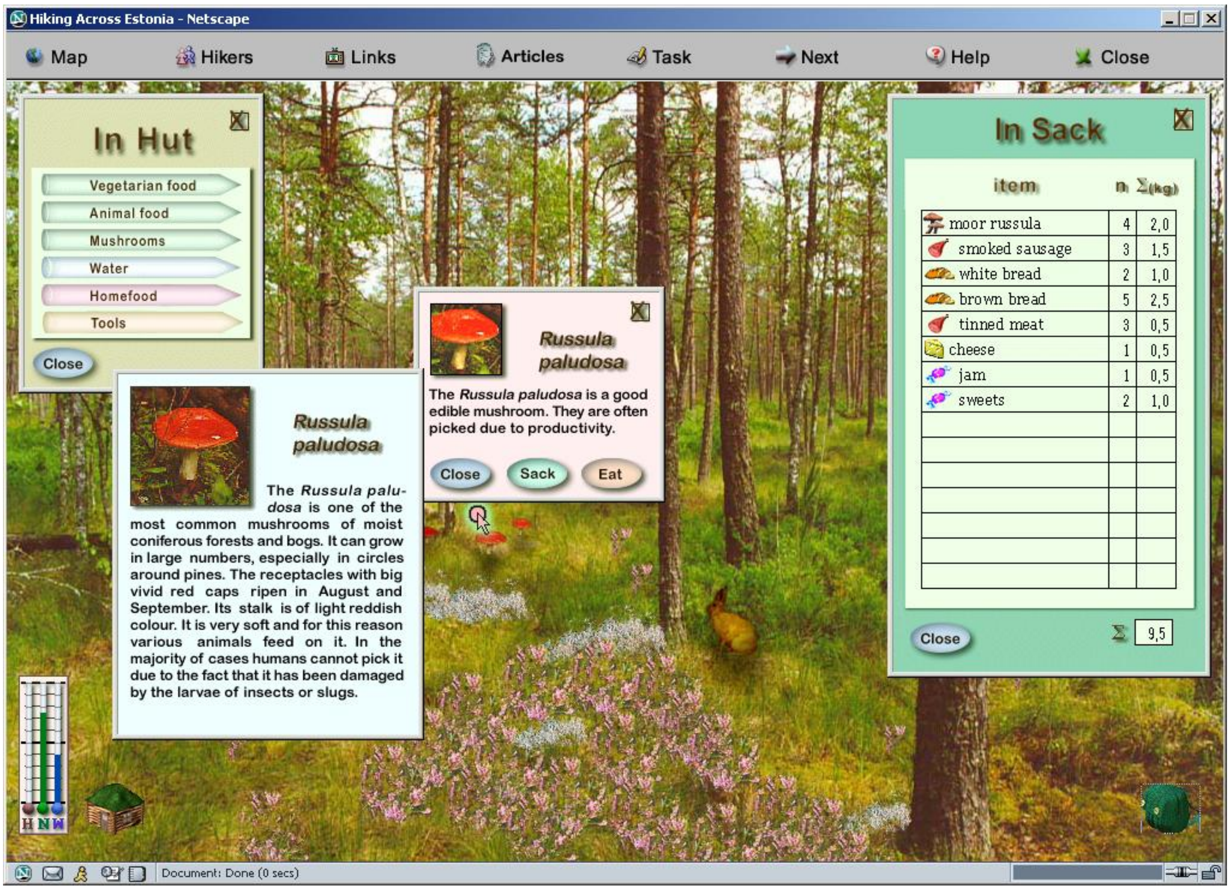


Figure 4. Bog with opened supplementary materials

## 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.

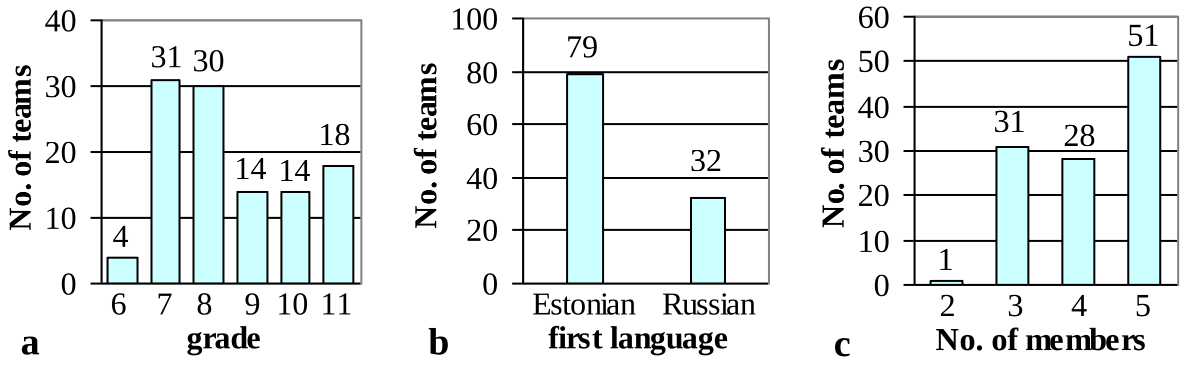


Figure 5. The distribution of finished hiking teams by grade (a), first language (b) and the number of members (c)

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 8$^{th}$ grade achieved 49% and teams from the 11$^{th}$ 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.

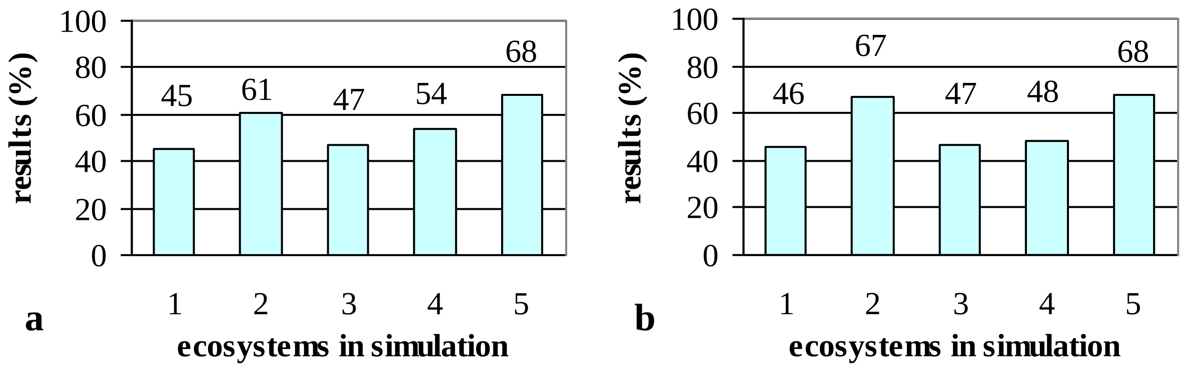


Figure 6. The results of basic school (a) and high schools (b) students on the simulation

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 11$^{th}$ grade students increased most but the learners from the 7$^{th}$ and 8$^{th}$ 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.

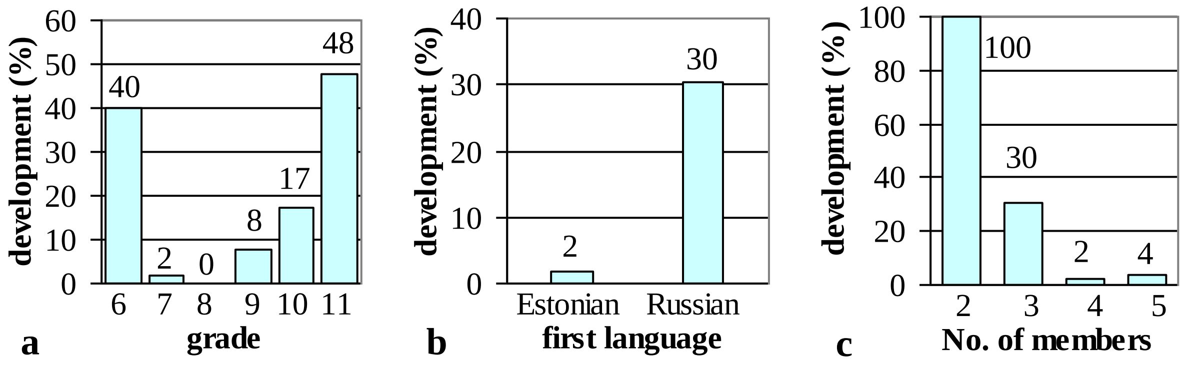


Figure 7. The development of skills to analyse graphs according to students' grade (a), first language (b) and the number of group members (c)

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 $9^{th}$ and $10^{th}$ 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 covariates. 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 is based on a virtual hike consisting of 30 problem solving tasks in certain order. Each problem has a slightly 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.

**ACKNOWLEDGEMENTS**

This work was supported by the ESF grant 4473 and MER funding 0182542s05.

**REFERENCES**

Alessi, S. M. & Trollip S. R. (1985). Computer-based instruction. Methods and development. New Jersey, Englewood Cliffs: Prentice-Hall.

Brooks, J. (1990). Teachers and students: constructivists forging connections. Educational Leadership, 47, 68-71.

Carroll, J.M. & Mack, R.L. (1984). Learning to use a word processor by doing, by thinking, by knowing. In J.C. Thomas & M. L. Schneider (Eds.). Human Factors in Computer Systems (pp. 13-51). Norwood, NJ: Ablex.

Cohen, L., Manion, L., & Morrison, K. (2000). Research methods in education. 5th Edition. London: Routledge Falmer.

Corderoy, R. M., Harper, B. M., & Hedberg, J. G. (1993). Simulating algal bloom in a lake: an interactive multimedia. Australian Journal of Educational Technology, 9, 115-129.

De Jong, H. & Rip, A. (1996). The computer revolution in science: steps towards the realization of computer-supported discovery environments. Artificial Intelligence, 91, 225-256.

Frese, M., Albrecht, K., Altmann, A., Lang, J., Papstein, P.V., Peyerl, R., PruÈmper, J., Schulte-GoÈcking, H., WankmuÈller, I., & Wendel, R. (1988). The effects of an active development of the mental model in the training process: experiment al results in a word processing system. Behaviour and Information Technology, 7, 295-304.

Gimblett, R, Daniel, T., Cherry, S., & Meitner, M. J. (2001). The simulation and visualization of complex human-environment interactions. Landscape and Urban Planning, 54, 63-79.

Harper, B. (1997). Building technology supported learning environments. Information Transfer, 17, 2, 37-42.

Huppert, J., Yaakobi, J., & Lazarowitz, R. (1998). Learning microbiology with computer simulations: students' academic achievement by method and gender. Research in Science & Technological Education, 16, 231-245.

Kamouri, A.L., Kamouri, J., & Smith, K.H. (1986). Training by exploration: facilitating the transfer of procedural knowledge through analogical reasoning. Journal of Man-Machine Studies, 24, 171-192.

Lazarowitz, R. & Tamir, P. (1994). Research on using laboratory instruction in science. In D. Gabel (Ed.) Handbook of research in science teaching and learning (pp. 94-128). New York: Macmillan.

Mertens, D. M. (1997). Research methods in education and psychology. Thousand Oaks, California: Sage Publications.

Needels, M. & Knapp, M. (1994). Teaching writing to children who are underserved. Journal of Educational Psychology, 86, 3, 339 – 349.

Oppermann, R. & Simm, H. (1994). Adaptability: user-initiated individualization. In: Oppermann, R. (Ed.). Adaptive User Supporting Ergonomic Design of Manually and Automatically Adaptable Software. Hillsdale, NJ: Lawrence Erlbaum.

Roberts, N., Anderson, D., Dean, R., Garet, M., & Shaffer, W. (1983). Introduction to computer simulations. Reading, MA: Addison-Wesley.

Sarapuu, T. & Pedaste, M. (2001). A pilot study of the web-based environmental simulation. Proceedings of SITE2001 – March 5-10, 2001 Orlando, Florida. Association for the Advancement of Computing in Education, Norfolk, USA, 2558 – 2562.

Margus Pedaste
Science Didactics Department
University of Tartu
Str. Vanemuise 46-211
Tartu 51014
Estonia
Email: pedaste@ut.ee

Tago Sarapuu
Science Didactics Department
University of Tartu
Str. Vanemuise 46-211
Tartu 51014
Estonia
Email: tago@ut.ee