RESEARCH NOTE

The Factors Influencing the Outcome of Solving Story Problems in a Web-based Learning Environment

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The aim of the present study was to investigate those factors influencing performance in solving story problems in a web-based environment. A situational simulation, "Hiking across Estonia," was explored by two samples of voluntary groups of students, comprising 65 and 50 groups, respectively. They solved 25 ecological and environmental story problems and filled in a pre-test and post-test that evaluated problem-solving skills. The groups were clustered according to their characteristics and performance into five clusters: "slow learners," "quick learners," "successful learners," "smart learners," and "ineffective learners." The clusters were provided with different types of supportive notes and the sequence of problems was rearranged according to the students’ initial results in the first four problem-solving tasks. These treatments demonstrated statistically significant improvements in the outcome in solving story problems in small groups. The main factors determining the effectiveness of problem solving were: (i) time spent on learning; (ii) initial skills in problem-solving; (iii) the presence of support in enhancing situation awareness; (iv) graduated problem tasks sequenced on the basis of complexity and difficulty; (v) ratio of genders in a learning group. However, the importance of these factors depended on the cluster and, therefore, it can be concluded that the design of problem-solving instruction has to be adapted according to the clusters’ characteristics.

Introduction

Among the many problem types (see Jonassen, 2004; Robertson, 2001) used in instruction we are interested in story problems, probably they are the most common type of problem in school. Many studies of the design, theory, and characteristics of these problems have been carried out (see Hegarty, Mayer, & Monk, 1995; Jonassen, 2000, 2003; Lucangeli, Tressoldi, & Cendron, 1998; Sherrill, 1983; Zweng, 1979).

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However, new challenges have been created in determining those factors that influence the learning outcome in solving story problems in a web-based environment and, especially, in the context of ecology and environmental education. Here, we outline the importance of context because, in general, story problems are also used in mathematics, chemistry, and physics. In learning biology, students become acquainted with numerical relations that are not obvious and constant and they are sometimes represented only qualitatively, not quantitatively. Instead of clear formulae and data, solving story problems in biology often starts with analysing not only text, but also visual information: tables, graphs, figures, and photographs. Our study was designed to find those factors that have a statistically significant influence on the outcome of solving biological story problems in a web-based learning environment.

The main characteristic feature of story problems is that information about the problem, including mathematical values, is embedded in a brief story (Jonassen, 2000). Sherrill (1983) distinguished four stages in solving a story problem: (i) identifying key words in the story; (ii) selecting an appropriate algorithm and sequence to solve the problem; (iii) applying the algorithm; (iv) evaluating the results. The most critical stage in this list is the first one, where learners often attend to unimportant phrases in the story or focus too closely on surface features of the problem and, therefore, fail to select the correct algorithm or transfer previously used solutions to the new context or feature (Sherrill, 1983; Woods, Hrymak, Marshall, Wood, Crowe, Hoffman, et al., 1997). Due to this, the process of analysing both verbal and visual information in a story problem is probably the most crucial and important factor influencing the solution.

Mayer (1981) concluded that there are 25 general families among more than 1,000 algebra story problems and that each of them has a number of templates applicable in solving the problems. Later, these descriptions of stories and related algorithms were called problem schemas (Riley & Greeno, 1988). Marshall (1995) also studied the structure of story problems and found five different schemas in mathematical contexts embracing both semantic and situational information that form the basis for selecting correct solving strategies. These 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. Although these schemas have been studied in learning simple mathematical problems, there is much in common with story problems in biology. For example, the changes in quantity in large groups or their subgroups are similar in an environmental and ecological context, but this information is mainly just the basis for combining different ecosystems. Finally, the relations have to be applied in making a prediction that is comparable with applying a generalization in a new situation. According to this synthesis, we can conclude that story problems in biology are usually more complex than in mathematics and generally contain a number of schemas of simple and well-structured story problems. Although, in accordance with Mayer’s (1981, 1982) work, which described many more types of problem strategies
than Marshall’s five schemas, it is not relevant to differentiate only five schemas of story problems and in the biology context more schemas are needed.

Blessing and Ross (1996) demonstrated that even experienced problem solvers have significant difficulties in understanding the deep structure in the content of a story. Therefore, we have focused on students’ analytical skills in analysing stories, which is the most crucial stage of problem solving. In a highly complex approach, Lucangelli et al. (1998) distinguished five capacities that are required to effectively solve story problems: (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; (v) the capacity and willingness to evaluate the procedure applied to problem solving. The first three aspects in this list can be compared with “identifying” and “defining the problem” in Bransford and Stein’s (1984) model of an “ideal” problem solver. The first idea represents the analysis of textual information, the second describes the ability to analyse visual data and translate between visual and non-visual information, while the third item involves combining all of them in understanding the problem in a broad context. The latter directs learners to carry out experiments that have to be evaluated in order to make conclusions. We can generalize that analytical skills, including both analysis of textual and visual information, form one of the key elements that has to be studied in describing the process of solving story problems in biology. This conclusion was also supported by the findings of Mayer (1982), who studied some aspects of learners’ difficulties in solving simple story problems and found that it was easier for students to assign a value to a variable than understand the relations between variables. Moreover, students tended to convert uncommon problem types into common ones, rather than develop new schemata to solve the particular problem.

Smith (1991) has described external and internal factors that have an influence on problem solving that are applicable to both traditional and computer-based learning. External factors comprise the problem representation and the learning environment, while internal factors include the individual characteristics of problem solvers.

The well-studied external factors of problem solving are structuredness, complexity, domain specificity, and type of representation (see Jonassen, 2000). All these describe a problem, but do not pay attention to the learning environment that frames the task. Therefore, we suggest integrating the model of complex problem solving of Funke and Frensch (1995). They have defined complex problem solving as an interaction between a problem solver and a task in the context of an environment. The learning environment may contain additional information, resources, disturbances, feedback, cooperation, peer pressure, and other factors (see Brehmer, 1995). The task includes factors that affect the structure of the problem: ill- or well-structured, simple or complex (see Newell & Simon, 1972; Simon, 1978), transparency of the task (see Funke, 1995), and context—familiarity or semantic embeddedness (see Huber, 1995).

Internal factors that have a strong influence on learning are experience, cognitive variables, and non-cognitive variables, according to the classification of Funke and Frensch (1995). Jonassen (2000) interpreted the experience factor as containing
aspects of familiarity plus domain and structural knowledge expertise: “Have students solved similar types of problems before” and “Do they know what strategy has to be applied for successful problem solving in this situation?” This factor enables expert problem solvers to apply problem schemas automatically, while novices have to develop the schema and may fail at this stage (see Sweller, 1988). The latest research in computer-based problem solving has indicated that while in classroom environments a teacher guides students towards experience, in multimedia-based environments the importance of the teacher is minimized and the learning environment has to act as a facilitator (Zhang, Chen, Sun, & Reid, 2004). Furthermore, in the last decade it has been demonstrated that not only the physical, but also the social environment plays a very important role in the learning process. It means that the internal and external factors are interrelated and affect the outcome more than just the sum of these factors. The learner is in social interaction with other students in a collaborative learning group and/or with virtual people or adaptive support mechanisms in the computer-based learning environment. Moreover, in some studies that support by the environment that enhances students’ situation awareness, either contextual or task and process, has come to be regarded as one of the most important factors influencing the computer-based learning process (see Pedaste & Sarapuu, 2006; Reid, Zhang, & Chen, 2003; Veermans, de Jong, & van Joolingen, 2000; Zhang et al., 2004). In this context, situation awareness involves learners’ knowledge of the opportunities of a learning environment and their understanding of why and how to apply available resources, virtual tools, feedback, etc. Situation awareness is also related to learners’ metacognitive knowledge of 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 with the appropriate tools?” (Flavell, 1979; Kentridge & Heywood, 2000). Reid et al. (2003) clarified that only meaningful learning in a simulation environment can direct a learner to the preferred learning outcomes. Metacognition can be regarded as a prerequisite for meaningful learning and, therefore, Jonassen (2000) selected it as one internal factor influencing problem solving outcomes. One possibility to support awareness and metacognition in solving computer-based story problems is making use of the IDLE tool (Bell, 1999). It provides learners with a list of predefined steps that have to be followed throughout the whole problem solving process to enhance learners’ metacognition. However, our studies have concentrated on identifying key factors and their relations. Therefore, we were especially interested in the situation awareness developed during the analysis of a particular story.

The cognitive variables in the classification of Funke and Frensch (1995) denote initial knowledge and skills concerning the problem task and the context in which it has to be solved. When elaborating cognitive variables, Jonassen (2000) focuses on the differences in students’ learning styles, for instance, he finds that field independence, cognitive complexity and flexibility, and ways of thinking (e.g. analytical thinking) interact strongly with problem solving process. In our study the cognitive variables deal with a 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 necessary to organize learning
in small groups. The proposed non-cognitive factors, students’ self-confidence, perseverance, motivation, and enjoyment (Funke & Frensch, 1995), or epistemological beliefs (Jonassen, 2000) were not of interest in our research.

In the present study the individual internal factors of students working in a small group formed the internal factors. In addition, there were other factors characterizing each particular group. According to the socio-cultural perspective, learning in groups improves 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, Messer, Light, & Littlejohn, 1995). It has also been demonstrated that learners who understand little about the immediate problem but work cooperatively may generate multiple perspectives and coordinate them to synthesize the correct solution (see Chiu, 2000; Stodolsky, 1984). Therefore, we can conclude that solving story problems in a group should be more effective than individual problem solving.

In talking about the many potential advantages of cooperative learning some important factors influencing the performance of groups have to be considered. For example, gender (Berg & Calderone, 1994; Strough & Berg, 2000), age (Berg, Strough, Calderone, Sansone, & Weir, 1998), and the nature of the relationships with others (Strough, Berg, & Sansone, 1996). In our studies we have concentrated on those differences deriving from gender. Strough and Berg (2000) studied the effect of gender on collaborative learning process and demonstrated that pre-adolescent girls shared their work more than boys in a team. Boys, on the other hand, often focus on dominance and asserting themselves at the expense of others (Leaper, 1991).

Both types of factors influencing problem solving, external and internal, have been well studied. However, there is lack of information concerning some aspects of both types: (i) the characteristics of learning groups; (ii) the presence and type of support. These were the aims of our investigation. The following research questions were formulated.

- What are the internal and external factors of learning groups that influence the outcome of solving story problems in a web-based environment?
- What are the factors related to instructional support that enhance performance in problem solving?

**Methods**

**Participants**

The present study was divided into two parts. Therefore, two different samples were selected to investigate the factors influencing the development of skills important in solving story problems. The first sample contained 262 students who formed 65 groups of from three to five learners. The results from these groups were used as the basis for the second part of the study. The second sample consisted of 194 students in 50 teams, also containing from three to five members. There was no statistically significant difference between the two sample groups according to the pre-test that
assessed problem-solving skills. Their initial achievements according to the pre-test (described below, see Figure 2) were 55% and 52%, respectively (this difference was not significant according to a t-test, $P = .217$). In both cases the students were from Grades 6 – 12 (age 12 – 18 years). The size of the teams in the first case was 4.0 on average, whereas in the second study it was 3.9 ($P = .524$). Participation was in all cases voluntary. The proportion of boys was also similar, 43% in the first and 40% in the second sample ($P = .701$).

Learning Environment

A situational learning simulation “Hiking across Estonia” (http://bio.edu.ee/matk/), developed in the Science Didactics Department at the University of Tartu, was used in both studies (Pedaste & Sarapuu, 2004). In this web-based environment learners take part in a virtual hike through five ecosystems: heath forest, grove, meadow, waterside meadow, and bog. Each ecosystem contains windows with supplementary material on about 200 species of plants, fungi, and animals. Text, photos, and figures presented in these materials serve as the sources of information to solve the story problems. The context of the learning simulation is based on general processes of ecology and environmental education on basic school biology courses: pollution of the natural environment (air, water, and soil), accumulation of pollutants, and waste management. A window with adaptive feedback is presented after solving each problem. The structure of “Hiking across Estonia” is similar to the goal-based scenario design proposed by Schank, Fano, Bell, & Jona (1994). They distinguished mission context and structure. The context contained the mission and cover story. In our case the mission context is to complete a virtual hike with higher scores than other groups of virtual hikers, while the story explains the situation in which the virtual hike takes place. The mission structure comprises the mission focus and scenario operation with embedded control, design, discovery, and explanations. In our learning environment students have to discover various problems during their mission, design their own strategy to solve these and obtain feedback as an explanation.

There are 25 problem-solving tasks, divided between five ecosystems, in this environment. Four tasks have been developed in each ecosystem to facilitate learning to solve story problems where only one type of additional visual information has to be applied, either analysis of graphs, tables, figures, or photos. In the fifth task, learners have to gain information from different sources and carry out the whole inquiry process in order to solve a complex problem. They identify the problem and develop hypotheses, design and run experiments using virtual tools (such as a microscope, magnifier, ruler, and instruments for analysing air, soil, water and for measuring the pH of the environment), collect data into tables and analyse these to find interrelations, which are the basis for making their decisions. Each of these complex tasks has been designed so that more than one strategy can produce a successful solution. In this paper we concentrate especially on these five complex problems, giving a survey of the whole process of solving story problems. An example of a complex task is presented in Figure 1.
In this particular case virtual hikers are informed that somebody has polluted a river but no one has taken responsibility for it. The learners as young scientists have to find the source of pollution using a bio-indication method. They take water samples from the river and examine them with a virtual microscope. The examples of indicator species are presented as additional material and they have to determine the number of individuals of these species in their samples of water. During the investigation they have to collect data on invertebrates into a table. However, a number of mistakes can occur in counting objects under a microscope, and the learners have to find methods to avoid these. After data collection, the students analyse information from different parts of the river and find that in some regions the pollution is higher and in others lower. At this stage they have to categorize the numerical data in order to make generalizations. Finally, they have to take into account the flow of the river and decide where most of the pollution originates.

For our studies it was important that the simulation “Hiking across Estonia” made it possible for researchers to record students’ activities in a database. That enabled us to analyse the learners’ results, improve the learning environment, and develop a support system for different types of learning groups (see Pedaste & Sarapuu, 2004, 2006; Sarapuu & Pedaste, 2001). We had two samples in the present study: the first one used the learning environment without any support, whereas the second one was
provided with a support system. The system enabled to implement two types of activities, rearranging the sequence of the tasks and adding supportive notes. Initially the problems in each of the five ecosystems were ordered on the basis of their level of difficulty, evaluated by the students in a former study (see Sarapuu & Pedaste, 2001). However, the difficulty level of ecosystems was balanced. For the second study a different sequence was developed for two particular groups: easier problems based on the analysis of a certain type of visual information were presented in the first ecosystem, whereas more difficult ones were given later. As a result of this rearrangement, the difficulty levels of the different ecosystems were no longer equal. However, in all cases the position of the complex problems remained unchanged, for use in evaluating the development of problem solving skills during the application of “Hiking across Estonia.”

The system also allowed the addition of supportive notes before presentation of the tasks to be solved. Three types of notes were developed; two to enhance learners’ contextual awareness within the learning environment and one to improve their task and process awareness of the problem solving process. The first set of notes on contextual awareness contained guidelines for finding appropriate additional materials or tools to solve a problem. The second set asked the learners to pay more attention to checking their answers on the basis of the facts available from different sources in “Hiking across Estonia” before submitting them. The notes on developing task and process awareness had suggestions on how to select appropriate sources to solve a problem and how to analyse the information in the light of a particular problem or relate different facts.

Procedures

In both studies the groups of students were composed of three to five volunteers. The groups registered for the virtual hike “Hiking across Estonia” and completed a questionnaire giving us information concerning the teams and their members. During the next week they had to complete an electronic pre-test, used to evaluate the groups’ initial level of problem solving skills. There was no time limit for performing these steps and altogether it took about an hour. Within the next five weeks the groups solved all 25 tasks in “Hiking across Estonia” in a time suitable for all members. However, in the second study some of the clusters of groups were provided with different types of supportive notes and with a rearranged sequence of story problems. This design was essential to evaluate the importance of particular factors influencing problem solving related to the learning environment. A post-test to evaluate the final level of problem solving skills was undertaken after completing the virtual hike. The content was similar to the pre-test.

Instruments

Both a pre-test and a post-test were developed for the first and second studies evaluating group problem solving skills. The internal reliabilities according to the
Cronbach $\alpha$ test were 0.76 for the pre-test and 0.81 for the post-test. There were four complex tasks in both tests analysing text, graphs, tables, photos, and figures. In the first two tasks the groups of students had to explain the relationship between observed variables and show how they made the decision. In analysing graphs and tables students were asked to explain whether the variables were correlated or not. Students were also asked to justify their decisions. Two photos of the same forest were presented to students in the third task, to evaluate their skills in analysing them. One photo was taken recently while the other was taken five years before. Learners had to find changes in the forest that had already occurred and predict what happen in the next five years. The fourth task was the most complex one and comprised analysing figures and a short text. During the inquiry process learners also had to analyse a table completed during data collection (Figure 2). They were asked to find correlations between the population sizes of three species in two ecosystems in an experimental and control group. Finally, the learners compared their initial findings with a text-based theoretical topic and developed a final solution. There were eight different questions in this complex task.

1. Text about the relations in an ecosystem.

2. Sampling grids of species in an experimental and control-ecosystem.

3. Table for collecting data.

4. Questions for data-analysis.

5. Predictions according to data-analysis.

6. Relations found by the comparison of theory and the results of the experiment (theory-building with explanations).

Figure 2. An example of a complex task in the pre-test evaluating problem-solving skills
The fourth task enabled us to evaluate the level of learners’ inquiry skills (capabilities) as it contained appropriate sub-tasks: students had to record observations, discuss 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 multiple choice answers in the test were scored by computer: 0 points for an incorrect answer, 1 point for a correct answer. The open-ended answers were categorized and rated as wrong (0 points), partly correct (1 point) or correct (2 points).

Data Analyses

The improvement in students’ problem solving skills when learning with the simulation “Hiking across Estonia” was assessed by one-way ANOVA on the basis of the pre- and post-test results. Spearman rank order correlations were used to clarify students’ development during the virtual hike. Hierarchical cluster analysis was applied to classify the groups of learners on the basis of group characteristics and performance. In our studies the number of members in a group, the ratio of genders, and the average age of the members were used, as well as the groups’ problem solving characteristics, described next. Their answers to the story problems of the virtual hike, the time used for learning, and the results of the pre-test and post-test were evaluated in order to describe group performance in problem solving. General differences between the clusters were determined by discriminant analysis, which also provided us with information on some important factors influencing the outcome of learning to solve story problems. Wilcoxon signed ranks tests were carried out to determine general differences between specific answers in the pre-test and post-test and Mann–Whitney U-tests to compare student development in these two studies according to group.

Results and Discussion

First Study

The first study was carried out in order to assess learners’ development in problem-solving skills and also their skills in analysing different type of information needed to solve story problems. However, it revealed that different skills improved in different groups of learners. Therefore, we tried to determine the ability characteristics of various groups in order to create analogous groups with appropriate support in a second study. First, the groups of learners were clustered on the basis of their performance and group characteristics and, next, discrimination between these clusters enabled us to determine some important factors that had a significant impact on the effectiveness of problem solving.

Learner clusters. Learning in a web-based environment has to adapt to the characteristics of the students according to the findings of many studies (see, for
example, Veermans et al., 2000; Zhang et al., 2000; Reid et al., 2003; Quintana et al., 2004). Therefore, it is important to determine the presence of different groups of learners and detect those factors that influence their learning to solve story problems. In our study hierarchical cluster analysis was used to cluster the groups of learners. In the first study the learning differences of the clusters were important in selecting the factors to develop the support for the second study. In the second study the clusters were determined by discriminant analysis on the basis of their problem solving results and the characteristics of the group after solving the fourth task of the virtual hike scenario in order to provide the groups of learners with appropriate sequences of story problems and supportive notes. That made possible an evaluation of the influence of these factors on the outcome of problem solving.

In the first study the groups were divided into five clusters (Figure 3). Data about the hiking teams, the results from the pre-test and post-test, and their achievements in problem solving tasks during the virtual hike were used as independent variables for clustering.

A description of the clusters is presented in Table 1. One cluster (A) of six groups out of 65 was differentiated from the others very nearly at the root of the cluster tree. Since they spent much more time on learning but obtained similar results as the others on average, this cluster was termed “slow learners.” The other groups were classified into four sub-clusters (B–E). A comparison of the problem solving strategies and the results in solving the problems in the tests and virtual hike enabled us to develop an adapted support system. According to the analyses, the groups in two clusters (C and D) did not need support because their problem solving skills improved considerably and they also applied different methods to analyse the data that are comparable with inquiry capabilities (Zachos, Hick, Doane, & Sargent, 2000): they formulated many hypotheses, made notes, found effective strategies to
search for relations between variables in a table or figures, analysed whether they could have made any mistakes, and checked their answers carefully before submitting these for assessment by the program. These groups differed mainly in two characteristics: the groups in cluster C took more time than those of D and applied fewer different methods in solving the problems. The outcomes of learning were good in both cases. Therefore, cluster C was termed “successful learners” and cluster D “smart learners.” However, the number of groups in these two effective clusters was less than half, 23 groups out of 65.

Clusters B and E spent less time on solving the problems than the other two. However, the groups in cluster B were successful, while those in cluster E were not. Therefore, we termed cluster B “quick learners” and cluster E “ineffective learners.” The groups of “slow learners,” “quick learners,” and “ineffective learners” were provided with two types of support. First, the sequence of the tasks was rearranged because the problems were too difficult at the beginning for “slow learners” and “ineffective learners,” who formed more than half of all groups (39 of 65). In addition, it was possible to present supportive notes automatically before presenting each problem. One set was designed to enhance contextual awareness in the clusters “quick learners” and “ineffective learners,” whereas “slow learners” were provided with notes to develop their task and process awareness. The notes on contextual awareness contained information about the available sources in the simulation “Hiking across Estonia” or reminded students of the need to pay more attention to these materials. The notes on task and process awareness stressed the strategy that should be used in analysing additional texts, graphs, figures, tables, or photos. However, these notes did not give answers to any particular problem; they merely suggested that certain materials should be used or explained how to use them.

Determining the factors influencing problem solving. The clusters determined by hierarchical cluster analysis demonstrate the diversity of learning groups in a sample

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### Table 1. Descriptive statistics of the clusters of learners identified in the first study

<table>
<thead>
<tr>
<th>Cluster name</th>
<th>n</th>
<th>Average result on the virtual hike (%) (max = 704 points)</th>
<th>Average time spent solving a problem (min)</th>
<th>Development of problem-solving skills during the virtual hike ($r$)</th>
<th>Development of problem-solving skills: difference between pre- and post-test (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>67</td>
<td>39</td>
<td>0.091</td>
<td>9.8</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>95</td>
<td>15</td>
<td>0.099</td>
<td>10.3</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>60</td>
<td>27</td>
<td>0.214</td>
<td>12.5</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>60</td>
<td>18</td>
<td>0.406&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.0</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>43</td>
<td>10</td>
<td>0.197</td>
<td>3.5</td>
</tr>
</tbody>
</table>

<sup>a</sup>Statistically significant correlation at $P = 0.05$. 

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of voluntary learners. The reliability of these five clusters was analysed in the second study, described below. These clusters are either effective or not in learning with “Hiking across Estonia.” Even more, it is possible to divide the teams into more or less effective groups and describe their difficulties on the basis of the results within the virtual hike problem solution and tests. In addition, we have information from the registration forms. Therefore, using discriminant analysis is appropriate in selecting those factors that play an important role in the outcome of solving story problems.

Three first discriminant functions together described 94% of the variance in the clustering results and four functions were enough to achieve 100%. However, according to Wilks’ test the first two functions were enough to describe the whole system ($P < .01$). The two functions that were dropped in the following analyses were most strongly correlated with learners’ grade and number of members in a team. Therefore, these characteristics of the group play only a minimal role in determining the success of learning to solve story problems in a web-based environment.

The first two functions discriminated characteristics that have a strong influence on the outcome of problem solving. The first function had the strongest absolute correlation with the time spent on solving problems ($r = .765$), achievement in solving story problems ($r = .607$), and the most complex task of the pre-test ($r = .338$). The second function mainly correlated with general results of the pre-test ($r = -.551$), skills in analysing photos ($r = -.524$), graphs ($r = -.506$), and tables ($r = -.487$), and ratio of boys to girls in a team ($r = .512$). The variable “skill in analysing photos” failed in the tolerance test and was not included in the final functions determined without the number of team members and their grade. These two functions described 90% of the variance:

Function 1: $C = 0.71T + 0.54ProS + 0.25TabS - 0.25PreS$
+ $0.21FigS + 0.06GraS + 0.01G$ ($\chi^2 = 83.3, P < .01$).

Function 2: $C = -1.65PreS + 0.88FigS + 0.63G + 0.48ProS$
+ $0.17TabS + 0.13GraS + 0.02T$ ($\chi^2 = 39.0, P < .01$).

Where $C$ is the cluster of learner groups, $T$ is the time taken to solve the problems, $ProS$ is the problem solving achievement in the first four tasks in the virtual hike, $PreS$ is the problem solving achievement in the pre-test, $TabS$ is the result for analysis of tables in the pre-test, $FigS$ is the result for analysis of figures in the pre-test, $GraS$ is the result for analysis of graphs in the pre-test, and $G$ is the ratio of boys to girls in a team.

Here, the time spent on problem solving means the average time taken to solve the first four story problems in the virtual hike simulation. It was hypothesized that the pre-test by itself could not evaluate all the factors that are important in determining the outcome of the learning process and, therefore, these four tasks were added to the analysis. Discriminant analysis proved that the time taken best characterized the clusters. However, the variable “time” can signify different meanings. In the case of “slow learners” it can indicate a lack of task and process awareness. The groups in this cluster spent 39 minutes per task, but their development in problem-solving skills
was not statistically better than in the other clusters. “Time” for “quick learners” or “ineffective learners” can mean a low level of contextual awareness, which could lead to a situation in which some answers submitted are not based on the facts available in the learning environment.

Initial problem solving skills are the second factor influencing the learning outcome in solving story problems. These skills can be divided into two parts: (i) general achievement in problem solution; (ii) the skills necessary to analyse information within the story of a problem. The first represents the learners’ ability to carry out the whole process of problem solving, but does not give any information on particular skills. The second defines various analysis skills that can play an important role for some clusters of learners. It is interesting that all five of the different skills are used in the functions, demonstrating that one of the skills is an important determinant for one cluster, the second for another, etc.

The last important factor influencing the learning process is the ratio of boys to girls in a team. It appeared that, generally, groups containing mainly girls had higher levels of achievement than those that did not. However, there was a very interesting cluster “quick learners” which contained more boys than any other group and had the best performance on the virtual hike.

In conclusion, the first study enabled us to design a support system for analogous clusters of groups in the second study. It consisted of two elements: (i) supportive notes to be presented before certain learning tasks; (ii) rearranging the sequence of story problems. It appeared that different clusters needed different support, while some of these did not need guidance at all in problem solving in small groups using a web-based learning environment, “Hiking across Estonia.” This means that support systems should be adaptive, as proposed by many researchers (Reid et al., 2003; Veermans et al., 2000; Zhang et al., 2004). The support needed by different clusters depended on their characteristics (see Table 1) and discriminant functions describing those factors that had a significant influence on clustering of the groups. Some of these groups were able to organize their work in an effective way, whereas others needed to be guided in assigning various roles in cooperative work (Cohen, 1994) or implementing specific strategies (Barnes & Todd, 1977; Cazden, 1988; Forman & Cazden, 1985; Slavin, 1996). We also had to overcome problems that could result from the mix of genders in groups (see, for example, Leaper, 1991; Strough & Berg, 2000; Strough, Berg, & Meegan, 2001).

In accordance with our results and pedagogical theories mentioned above, the following actions were implemented in the second study.

- The cluster “slow learners” had no success in solving the more difficult problems. Therefore, the sequence of problems was rearranged; the simpler ones were presented first. These students also spent too much time on solving problems and so, subsequently, notes to enhance task and process awareness were added.
- The cluster “quick learners” spent little time and did not check their answers before submitting them and, obviously therefore, failed in solving the most
difficult problems based on analysing figures and tables. Thereby, notes on the need to verify their answers were added.

- The cluster “successful learners” used different methods to analyse data (a common characteristic of advanced problem solving strategies) and, due to this, improved significantly from pre-test to post-test. Apparently they did not need support.
- The cluster “smart learners” demonstrated significant development during solving the story problems in the simulation because they extensively applied different methods for analysing data and improved considerably on the tests. Therefore, they also did not need support.
- The cluster “ineffective learners” had major difficulties with complex problems, but also failed in solving simple ones. On the other hand, they solved problems too quickly and, therefore, the sequence of these was rearranged. Next, this cluster was presented with the simpler problems first, with notes to enhance their contextual awareness added.

Second Study

One of the main findings of the first study was that the levels of problem-solving skills in groups of learners were different and that there was a need for an appropriate sequence of problems and supportive notes. The second study was designed to evaluate the importance of the support system designed on the basis of the first study. The effectiveness of adapted support was measured by student development in their problem-solving skills.

Problem-solving skills. The initial level of problem solving skills was an important factor in determining clusters and, therefore, the development of skills to solve problems on the virtual hike or tests is presented cluster by cluster. Here we will introduce the results of the second study in comparison with the first, since it allows an evaluation of the importance of adapted support to solving story problems.

The clusters of learning groups in the second study were created by discriminant analysis on the basis only of the information on the registration forms and the first four tasks of the virtual hike. The results from the pre-test were not applied in order to make the student clusters independent of the test instruments. This approach enabled us to correctly classify 75% of the groups and provide them with appropriate supportive notes and sequences of the next 21 story problems.

The pre-test and post-test demonstrated that learners improved in solving complex problems in both studies. However, the improvement was statistically significantly greater in the second study (see Table 2). There was no statistically significant development among “slow learners,” “quick learners,” and “ineffective learners” in the first study, while they improved even more than the teams in the clusters “successful learners” and “smart learners” in the second study. For the latter we did not make any changes in the second study compared with the first; they received no supportive notes to enhance their situation awareness and all tasks were in the same sequence.
Table 2. Comparison of the results for solving one complex story problem of the pre- and post-test for the groups in different clusters in the first (without support system) and second (in which clusters ‘Slow learners,’ ‘Quick learners,’ and ‘Ineffective learners’ were supported) studies

<table>
<thead>
<tr>
<th>Cluster name</th>
<th>First study</th>
<th>Second study</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>$F$</th>
<th>$P$</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>$F$</th>
<th>$P$</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>13.8</td>
<td>13.5</td>
<td>0.0</td>
<td>n.s.</td>
<td>10.0</td>
<td>14.3</td>
<td>20.2</td>
<td>&lt;.01</td>
<td>36.9 &lt; .01</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>10.7</td>
<td>10.3</td>
<td>0.0</td>
<td>n.s.</td>
<td>11.7</td>
<td>14.7</td>
<td>4.5</td>
<td>&lt;.05</td>
<td>12.5 &lt; .05</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>11.2</td>
<td>14.1</td>
<td>3.9</td>
<td>&lt;.05</td>
<td>11.9</td>
<td>14.6</td>
<td>3.9</td>
<td>&lt;.05</td>
<td>2.1 n.s.</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>12.6</td>
<td>15.4</td>
<td>9.9</td>
<td>&lt;.05</td>
<td>12.4</td>
<td>14.3</td>
<td>4.2</td>
<td>&lt;.05</td>
<td>3.1 n.s.</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>9.0</td>
<td>10.2</td>
<td>0.4</td>
<td>n.s.</td>
<td>8.9</td>
<td>11.6</td>
<td>10.0</td>
<td>&lt;.01</td>
<td>41.2 &lt; .01</td>
</tr>
</tbody>
</table>
The smallest improvement in problem solving and inquiry skills in the first study occurred in the groups “ineffective learners,” which was also the biggest cluster, with 33 groups (51%). Due to the application of our support system, they improved more than the groups in any other cluster in the second study compared with the first one. In comparing the two studies only the clusters “successful learners” and “smart learners” had no statistically significant change. This result strongly suggests that better scores are produced with the support system, because it was not applied to the teams in those clusters who showed no difference in the two studies.

Spearman rank order correlations between the ordinal number of each task and the average result in each cluster for both studies were calculated in order to evaluate progress in solving five complex problems during the virtual hike (Table 3).

Table 3 indicates that student improvement during the virtual hike in the second study occurred for three clusters. “Slow learners” and “quick learners” demonstrated a much higher correlation compared with the first study, but these changes were not highly significant, because of the low number of teams in these clusters. As to the teams in the clusters “successful learners” and “smart learners,” it appeared that there were no statistically significant differences between the two studies. It should be remembered that these two clusters were not supported in the second study.

The development of problem solving skills in the cluster “ineffective learners” was remarkable. It was the biggest cluster in both studies (more than 50% of teams) and showed the highest Z-score when comparing the two studies (Z = 2.61, P < .01). It can be seen that the teams in this cluster had a more stable improvement in the second study compared with the first (Figure 4). This improvement was already

Table 3. Comparison of the improvement in solving five complex problems in the virtual hike in a predefined sequence by the groups in different clusters in the first (without support system) and the second (in which clusters ‘Slow learners,’ ‘Quick learners,’ and ‘Ineffective learners’ were supported) studies

<table>
<thead>
<tr>
<th>Cluster name</th>
<th>First study</th>
<th>Second study</th>
<th>Spearman correlation between the ordinal number of a complex task and the average result</th>
<th>Comparison of the two studies using the Mann–Whitney U-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td>First study</td>
<td>Second study</td>
</tr>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>–0.20</td>
<td>0.90a</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>–0.05</td>
<td>0.60</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>0.30</td>
<td>0.80</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>0.70</td>
<td>1.00a</td>
</tr>
</tbody>
</table>

aStatistically significant correlation at P = 0.05.
apparent at the beginning of the virtual hike, and this could have a positive effect on student motivation in using the learning environment. Thus, this motivational effect of using the notes might be a possible reason for the students’ improvement in solving complex problems (see Eggen & Kauchak, 1999). The supportive notes guided learners to certain ideas on how to gain success in solving story problems.

Similarly to the general development of problem solving skills, analytical skills showed a statistically significantly better improvement when applying the support system (Table 4). However, the support mainly had an effect on those skills required to analyse tables and figures, while the skills needed to analysis graphs and photos were already comparatively good in the pre-test. The comparison of the development of analogous clusters in the two studies was based on the Mann–Whitney U-test. This non-parametric test enabled the detection of statistically significant differences, although there were only a small number of groups in each cluster. In this context, analytical skills measured the students’ ability to find relationships between data presented in the form of graphs, tables, photos, and figures.

The cluster “ineffective learners” was the only one in which the groups demonstrated a significant change in all analysis skills. Even though they had improved in analysing graphs and tables in the first study without support, the development of these skills in the second study was much greater and their final ability to solve story problems was comparable to the more effective groups, “smart learners” and “successful learners.” It was remarkable that all the clusters that were supported in the second study had significantly better results compared with the first when considering the analysis of tables and figures. Story problems where problem identification was based on these types of visual information appeared to be the most complicated. Therefore, we can conclude that support to enhance learners’ general awareness and metacognition can outweigh their individual differences.
Finally, we can conclude that the second study proved the effectiveness of the support system designed on the basis of the results of the first study. Moreover, it enabled us to add two important factors to the list of factors influencing the development of problem solving skills when learning in small groups in a web-based learning environment. These are “the presence of a support system to enhance situation awareness” (either task and process, or contextual) and “an appropriate sequencing of the story problems arranged on the basis of their complexity and difficulty.”

Table 4. Comparison of the improvement in analysing graphs, figures, tables, and photos of the pre- and post-test by groups in different clusters in the first (without support system) and the second (in which clusters ‘Slow learners,’ ‘Quick learners,’ and ‘Ineffective learners’ were supported) studies

<table>
<thead>
<tr>
<th>Cluster name</th>
<th>First study</th>
<th>Second study</th>
<th>Development of analytical skills (%)</th>
<th>Comparison of the two studies using the Mann–Whitney U-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td>First study</td>
<td>Second study</td>
</tr>
<tr>
<td>Analysing graphs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>15</td>
<td>23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>18</td>
<td>23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Analysing figures</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Analysing tables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>50&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>10</td>
<td>33&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>24</td>
<td>23&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Analysing photos</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Slow learners</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>B. Quick learners</td>
<td>3</td>
<td>3</td>
<td>11</td>
<td>22&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C. Successful learners</td>
<td>6</td>
<td>3</td>
<td>17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>D. Smart learners</td>
<td>17</td>
<td>13</td>
<td>13</td>
<td>13&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>E. Ineffective learners</td>
<td>33</td>
<td>27</td>
<td>15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Statistically significant change according to Wilcoxon signed ranks test at the significance level 0.05.
Conclusion

Our results support the classification of factors influencing problem solving described by Funke and Frensch (1995) and Jonassen (2000), who distinguished external (learning environment) and internal (learner) factors. On the basis of the present study, it is possible to give a broader sense to both of these types. We have demonstrated the statistical significance of some internal factors that are measured at the group level instead of the level of individual learner, and external factors describing the importance of adapted support, rather than just the static learning environment. These results also relate to aptitude-treatment interaction (ATT) theory, which states that the best supportive effect for individuals involves treatments that differ in structure and completeness of instruction and have high and low ability measures (Snow, 1989). A high level of external control and well-defined sequences of learning seem to help students of low ability, but hinder those of high ability.

Learning groups obviously have some characteristics that do not change during learning: the age of the students, the number of members in a group, and the ratio of males to females. Our results have demonstrated that only the ratio of males to females has an important role in the outcome of solving story problems with small groups in a web-based environment. The groups containing mainly girls were more effective than those where boys prevailed. Nevertheless, this was not a limiting factor, because the differences disappeared when the groups with a higher number of boys were provided with appropriate support.

On the other hand, the groups could also be characterized on the basis of their initial knowledge and skills, which is normally evaluated as an individual internal factor (Smith, 1991). In our multistage approach learners’ knowledge and skills change during the process of learning and, therefore, the groups of learners should have a different type of support or even a different strategy for presenting learning tasks. In our second study we provided the initially unsuccessful clusters “slow learners,” “quick learners,” and “ineffective learners” with appropriate supportive notes and an improved sequence of problem solving tasks. The need for specific notes or a changed sequence of problems was determined from analysis of the results of analogous clusters in the first study. This approach made possible an evaluation of the importance of some factors concerning learning environment. Our results indicate that the time taken to solve problems and the initial level of both general problem solving ability and, particularly, analysis skills are the most important factors influencing learning to solve story problems.

In addition, the present results demonstrate that for some groups of students it is important to rearrange the sequence of the tasks and to provide them with supportive notes. However, these procedures have to be based on an analysis of actual needs. Thus, in our case, the first study served as a preparatory study to the second, in determining the required adaptive support system (see Pedaste & Sarapuu, 2006). The first study proved that the initial sequence of simple problems was only appropriate for about one-third of students, while the others needed a rearrangement of these problems.
The importance of rearranging the sequence of tasks has been studied for over 30 years (see Landa, 1974, 1976). In the current study, this action applied to groups in two clusters, “slow learners” and “ineffective learners,” who appeared to fail in the first study as a result of too difficult problems at the beginning of the learning cycle. In the second study these clusters demonstrated the highest improvement in problem solving and analytical skills. Moreover, “ineffective learners” were the only group in which all analytical skills improved.

Three clusters out of five in the second study were used to evaluate the role of supportive notes in enhancing learner skills necessary to solve story problems. These were provided with different notes developed on the basis of the difficulties found in solving problems by the analogous clusters in the first study. As a result of applying supportive notes to improve either contextual or task and process awareness, the clusters “slow learners,” “quick learners,” and “ineffective learners” developed their skills to solve story problems statistically significantly more than without any support. Therefore, we can conclude that internal individual differences between learning groups can be overcome by providing the learners with adapted support.

Our study has proved that both types of characteristics, group and environmental, have to be taken into account when designing an effective learning process to develop the skills necessary to solve story problems in a web-based learning environment. We can generalize that the most important factors influencing learning to solve story problems in simulation environments within small groups are: (i) time spent on learning; (ii) initial skills in problem solving; (iii) appropriate support to enhance situation awareness; (iv) a proper sequence of problem tasks according to their complexity and difficulty; (v) the ratio of males to females in a team.

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