The System of Questioning: Support for Acquiring Inquiry Skills in Applying Web-based Models

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Abstract: The current study was designed for analyzing the mechanisms that guide students in developing their skills to formulate research questions or hypotheses, and to plan experiments. Two web-based models ‘Ecological balance’ and ‘Changes of ecosystems’ were used by 391 students from the 8th grade (age 13-16). The comparison of pre- and post-test results demonstrated that the proposed structure of the worksheets is effective for developing students’ inquiry skills in applying computer-based models. However, one treatment group outperformed the second group in development of the skills to formulate research questions and plan experiments. The development of students’ questioning skills was higher if there were open ended questions before the correct examples on the worksheet. At the planning stage, some students improved if they were provided with guiding questions for designing experiments while the others had to analyze a “recipe” of activities. The appropriate structure of the worksheet depended on students pre-skills.

Introduction

Inquiry learning has become increasingly important approach for implementing science curriculum in many countries (see National Science Foundation, 2000; National Curriculum Online, 2008). One of the reasons of this is that there are a number of different skills and abilities that will be developed during the process of inquiry – problem solving skills, ability to explain data, critical thinking skills, and understanding of principles of science (Chiappetta & Russel, 1982; Saunders & Shepardson, 1987). Anyway, the most important advantage of this methodology is that students learn to work as real scientists do and also acquire new knowledge for themselves (De Jong, 2006). According to the National Science Foundation (National Science Foundation, 2000), inquiry learning is a process of understanding natural principles or solving a problem through asking questions, making discoveries, and testing these discoveries in search of new understanding. Thus, the process of inquiry is directly related to scientific discovery that has been studied for a longer time. The difference of discovery and inquiry learning occurs in the emphasis of the learning objectives. The main goal of discovery learning is to find a relation but the inquiry learning sets the accent to the process of discovery. It means that inquiry has been used for developing the skills of making discoveries rather than the discovery itself. However, it is appropriate to refer research in both areas.
The process of discovery can be divided into two main stages – hypothesis space and experiment space (Klahr & Dunbar, 1988). Klahr and Dunbar’s (1988) theory of ‘Scientific Discovery as Dual Search’ stated that the first one is for building hypotheses about scientific principles and phenomena and the second one for testing discovered concepts. They have also 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 formulating the hypothesis and after the first unsuccessful experiment turn back to make a new hypothesis whereas in other cases they carry out a number of experiments without generating new hypotheses. In our study, we concentrated on analyzing the processes of hypothesizing.

The stage of hypothesizing in broader meaning contains a number of sub-stages. In regard to the works of Harlen and Jelly (1997), Friedler, Nachmias and Linn (1990), and Padilla (1990) there can be distinguished the stages of identifying the problem, formulating research questions, formulating hypotheses, and planning the study. There could be some controversies to consider the planning stage as a part of hypothesis space because it is the actual link between hypotheses and experimentation. However, in the current study, we have included this stage because the revised hypothesis will be posed in accordance with realistic plans for testing it. At the same time, we excluded the stage of identifying problems from our study. The reason for that was derived from the general approach we used in classrooms. The students were provided with a short story where was embedded a clear problem that had to be solved in applying a computer-based model. Thus, there were no actual difficulties in identifying a problem but with formulating a correct scientific research question. However, in some studies, the stages of identifying problems and composing research questions are linked into one stage. For instance, Friedler, Nachmias and Linn (1990) described only the stage of defining scientific problems before stating the hypothesis and designing the experiment.

Padilla (1990) has divided all science process skills into basic and integrated skills. From the hypothesis space, only the observation needed for formulating problems is regarded as a basic skill whereas the others – skills of formulating research questions and hypotheses, and planning experiments – are integrated science process skills. In our interpretation, the formulation of scientific research questions is something between basic and integrated skills. The important difference of this stage compared with others is that it does not involve synthesis or integration of information from different sources. Therefore, we can consider it as a lower level skill compared with hypothesizing and planning that need synthesis of situational and scientific background information, and also involve abstract prediction of outcomes.

One of the key questions of inquiry learning for many years has been appropriate guidance given to the learners and it is still in a focus of research in this area (de Jong, 2006). Domin (1999) evaluated the effectiveness of expository versus open-inquiry in conducting experiments. In expository situation, students were provided with a detailed plan of activities and instructions that had to be followed correctly. This was a deductive approach where students did everything correctly but it was not essential to think about their learning process. They just used a “recipe” without analysis. In the expository situation, they had to formulate their own hypotheses and design an experiment. This was a really inductive open-ended process directed by the learners. Bransford and Donovan (2005) have found that the learners must be actively involved in constructing personal meaning from inquiry activities. It means that there cannot be very strict rules and open-ended approach should be more effective compared with a “recipe” in developing inquiry skills. These two methods of supporting learning process were evaluated by Priemer (2006). It was found that the more students preferred open-ended approaches the more they liked practical work. On the other hand, simple following of recipes did not incorporate scientific thinking and reasoning and, therefore, had no positive effect in developing students’ attitudes towards science. In our study, we did not interested in attitudes but focused on the development of inquiry skills.

In addition to the appropriate guidance, the outcome of inquiry process is mainly dependent on hypothesis generation. In broader meaning, it involves the analysis of a problem in order to formulate a research question and hypothesis. The final stage – hypothesizing – is a synthesis of information extracted from the situation, prior knowledge, and new information gained about the particular problem. Van Joolingen (1999) has observed it as the state where actual new knowledge will be formed and regards it as the most difficult process in discovery learning. It was also found that two main problems in formulating hypotheses were the lack of knowledge about the structure of a correct hypothesis, and low level of prior knowledge, for instance about possible variables. Van Joolingen (1999) applied hypothesis scratchpad as a cognitive tool for supporting hypothesizing – a correct structure of hypothesis was given to students and they had to fill in the form with appropriate words according to the particular situation. In our research, we made an adaptation of this supportive tool and presented a number of examples of hypotheses that contained all correct elements.
In this study, our aim was to give a significant contribution to solving the problems appeared in guiding students in hypothesis space when learning with computer-based simulations. Therefore, the following research questions were formulated:

i) Do computer-based models with accompanying inquiry worksheets develop students’ inquiry skills and domain-specific knowledge when the worksheets contain appropriate supportive elements?

ii) How does students’ improvement in skills to formulate research questions or hypotheses and to plan experiments depend on their characteristics?

iii) What types of worksheets and supportive elements are effective in developing inquiry skills of different students?

**Methods and Sample**

The current research was divided into pilot study and main study. The first one was carried out for validating the instruments. The students of the pilot study (n=59) were randomly divided into two groups. The group one filled in a pre-test that served as a post-test for the group two. In the same way, the pre-test of group two served as a post-test for the first group. The comparison of the results of two versions of the tests made it possible to prove that these are equally appropriate for measuring inquiry skills. Therefore, we could use one version as the pre-test and the second one as the post-test of the main study. In addition to combining the usage of tests, we also provided both groups with two different versions of worksheets for learning with computer-based models. These worksheets differentiated in their structure and built-in support. Both worksheets were randomly given to the group one and two. Thus, finally we had four different groups of learners. It convinced us that the pre- and post-test measured the development of students’ inquiry skills statistically equally in both cases. As a result of the pilot study, it was possible to say that the tests are valid for evaluating the differences of using two types of worksheets.

391 students from 23 different schools participated in the main study – 163 boys and 228 girls. Their age was 13-16 years (average 14.5). All students filled in the pre-test, applied two computer-based models with accompanying worksheets, and finally filled in the post-test. The pre- and post-tests assessed their domain-specific knowledge and inquiry skills related to the hypothesis space. All questions expected open-ended answers. There were four biological questions in the tests. Two of these were related with usage of one computer-based model and the other two were related with the second model. All these questions required the application and analysis of domain-specific knowledge. For instance, it was asked how and why is the number of pikes in a lake affected by the changes in the number of roaches. Six questions assessed students’ inquiry skills. Firstly, two stories were presented and students had to write three correct research questions on these basis. Next, two other stories formed the source data for writing three hypotheses about both of them. Students’ options included the selection of the numbers of analyzable squares and roads in one area (of whole area). Some of the species of lichens presented to students were not dependent on the level of nitrogen or sulfur oxides, while the same substances caused the changes in coverage of other species.

Two web-based models from the learning environment “Computer-based models in basic school science” ([http://mudelid.5dvision.ee/](http://mudelid.5dvision.ee/)) were applied in this study. This learning environment is composed by the company 5D Vision in cooperation with the Science Education Centre at the University of Tartu. One of these models, applied in this study, was about balance in an ecosystem (Fig. 1). The students had an opportunity to change the initial state of a lake ecosystem, particularly, in choosing the number of predatory fishes and those that belong to their food. After starting the simulation, the changes in the numbers of fishes through time were presented on a graph and animation. The model enabled to stop the simulation according to the needs of learners. The algorithm behind the simulation had a random parameter and, therefore, the results different experiments with the same initial parameters were not equal. However, it was possible to detect the related fluctuations of predators and their food objects if one of the populations did not die out very quickly. Each model was provided with a help web page for using a particular model and a domain specific theory page.

The second model, applied in our study, was for finding the sources of air pollution (Fig. 2). Students must analyze the coverage of different species of lichens on trees of a big forest. The data of these analyses had to be used for locating the factories that have been caused the air pollution. Students’ options included the selection of the numbers of analyzable squares and roads in one area (of whole area). Some of the species of lichens presented to students were not dependent on the level of nitrogen or sulfur oxides, while the same substances caused the changes in coverage of other species.
Two types of worksheets were composed for using the models. In both versions, a general scientific problem was given to the students and they had to define it according to the possibilities of the particular computer-based model. Next, students had to read a domain specific theory and to explore the model in order to compose research questions and hypotheses, and to plan an experiment for finding answers to the research questions. The plan had to be implemented for collecting data usable for making inferences and solving the problem. The first difference between two versions of the worksheets was in the tasks of composing research questions and hypotheses. There was a list of different research questions in the version “a” of the worksheet and students had to select all questions that were correctly formulated and answerable in using the model. The next one was an open-ended question for formulating hypotheses. In the version “b”, the types of questions were vice versa – the task for formulating research questions required an open-ended answer and examples were provided to support hypothesizing. The planning stage in two versions of worksheets was also set up differently. In the version “a”, students were guided with a number of questions that helped them in designing their experiment. This was also an open-ended task. The version “b” contained a stricter “recipe” for the particular experiment and students had to analyze it. Their main task was to explore the model and answer some concrete questions about it and to reason the activities that should be carried out for finding the answers to the proposed research questions. The validity of the worksheets was performed in an expert group discussion and with piloting.

Figure 1: The model for studying the changes in the balance between two species of fishes in an ecosystem (http://mudelid.5dvision.ee/kalad/).

Figure 2: The model for finding the sources of air pollution using the method of lichenoidication (http://mudelid.5dvision.ee/samblikud/).
All the data collected in the pilot and main study was analyzed with SPSS 15.0. Paired samples t-test was used for comparing the means of the students’ results in the pre- and post-tests. Independent samples t-test was applied for finding the differences between various groups of students. In some cases, the analysis of covariance was implemented for showing the improvement of particular groups of students without the variation of the gender and their initial skills that were used as covariates.

Results and Discussion

The pilot study confirmed the validity of the instruments developed for the study. The independent samples t-test showed that the general result of the two groups was not different in the case of pre-test (t=0.87, p>0.05) and post-test (t=-0.94, p>0.05). For each inquiry skill, the differences were calculated and assessed separately with the tests – all these were not statistically significant. In addition, the differences in the post-test results of two groups who used two different types of worksheets were calculated. There were 20 students who used the first version of the worksheet. Twelve of them filled in the version “a” of the pre-test and the others the version “b”. Their results of both tests were not statistically significantly different (t=1.61 in the pre-test and t=-0.25 in the post-test). Similar results appeared in the case of students who used the second version of the worksheet (n=29, t=-0.99 in the pre-test and t=-1.38 in the post-test). It revealed us that these two versions of the tests were equally usable for pre- and post-testing in different treatment groups of the main study.

In the main study, we evaluated the development of students’ inquiry skills related to the hypothesis space. However, it was also demonstrated that not only the skills but also students’ domain-specific knowledge improved as a result of using the web-based inquiry models with students’ worksheet. The outcome of knowledge-based questions in the pre-test was 3.1 points out of 8 and in the post-test 4.2 points out of 8 (t=-9.55, p<0.01). It showed that this inquiry process is applicable for acquiring new knowledge as it is stated in the goals of this approach (National Science Foundation 2000).

In our study, the skills to pose research questions, formulate hypotheses, and plan an experiment were assessed. In general, the level of students’ inquiry skills developed statistically significantly when comparing the results of the pre- and post-tests (Tab. 1). However, besides the questioning and planning, the skill to formulate hypotheses did not improve statistically significantly. The reason could derive from the very low initial skill of formulating research questions. Our previous studies have confirmed that the skills to formulate research questions and hypotheses are related with each other but a minimum level of the skill of questioning is needed for developing the hypothesizing skill (Mäeots et al., 2008). It means that these skills will increase only on the basis of a sufficient initial level of the skills to formulate research questions. In this study, a practical implementation of the partially repeated result provided us with an opportunity to divide the students into at least two groups according to their pre-skills, while one group concentrated on questioning and the second one on hypothesizing. Moreover, referring Padilla’s (1990) work, we can conclude that hypothesizing corresponds to the integrated science process skills that need more abstract thinking and synthesis, when the skill of questioning belongs more to the basic science process skills.

### Table 1: The development of students' (n=391) inquiry skills related to the hypothesis space in using computer-based models with additional worksheets.

<table>
<thead>
<tr>
<th>Inquiry skill</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>t-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Formulating research questions (max=12)</td>
<td>1.15</td>
<td>1.97</td>
<td>2.29</td>
<td>2.94</td>
</tr>
<tr>
<td>Formulating hypotheses (max=12)</td>
<td>4.20</td>
<td>3.28</td>
<td>4.24</td>
<td>2.81</td>
</tr>
<tr>
<td>Planning experiments (max=18)</td>
<td>6.42</td>
<td>4.40</td>
<td>9.61</td>
<td>5.01</td>
</tr>
<tr>
<td>General development of inquiry skills (max=42)</td>
<td>11.77</td>
<td>7.03</td>
<td>16.14</td>
<td>8.07</td>
</tr>
</tbody>
</table>

Next, we concentrated on the differences of outcomes of two groups who used different types of worksheets with the computer-based models. The students performance was analyzed only in respect of their improvement in skills to formulate research questions and to plan experiments while, in generally, both increased...
statistically significantly. According to the results of the ANCOVA test, it was detected a slightly higher improvement of both skills in the second group (Tab. 2). This was the group who provided with questions that required the open-ended answers in posing research questions and, next, a list of hypotheses for making a selection was given. In the first group, the list was given in the case of questioning and open-ended answers were in hypothesizing stage. The students of the second group had to think in more open-minded way in completing the first task – that helped to develop their own ideas and to recall previous knowledge about particular domain and whole inquiry process. In the first group, the given options restricted students’ thinking and, therefore, they did not improved so effectively. This result supports the findings of Priemer (2006) who has stated that open-ended approach directs students to thinking and reasoning that is needed for actual learning. However, at the stage of planning, the second group was provided with a “recipe” that was analyzed step by step for understanding the experiment. In the first group, the plan was derived from questions that were asked from the students. It demonstrated that the students who did not have to develop their own plans outperformed the others. The reason of it could be that the too open-ended process for planning was not appropriate for the students. However, students' skills can develop more if they have higher level initial planning skills. The initial level of particular skills was the most important covariate in ANCOVA model calculated for the development of the planning skill. Therefore, we analyzed if the appropriateness of particular types of worksheets depends on the students’ pre-skills. This could also reveal that there is a hierarchical system of supportive elements that have to be used in accordance with the level of students’ skills.

<table>
<thead>
<tr>
<th>Inquiry skill</th>
<th>Development of the first group</th>
<th>Development of the second group</th>
<th>F-value</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Formulating research questions (max=12)</td>
<td>0.99</td>
<td>2.49</td>
<td>1.33</td>
<td>2.88</td>
</tr>
<tr>
<td>Planning experiments (max=18)</td>
<td>3.04</td>
<td>5.04</td>
<td>3.34</td>
<td>4.84</td>
</tr>
</tbody>
</table>

Table 2. The differences in the development of students' inquiry skills in two different treatment groups (n<sub>1</sub>=207 and n<sub>2</sub>=184) of the study found with ANCOVA analysis where pre-skills and gender were used as covariates.

The results of the independent samples t-test demonstrated that there was a strong influence of students’ initial inquiry skills on the development of these skills. Therefore, the students were divided into two groups according to the mean results of the pre-test. In the case of the both skills that were developed significantly in the current study, a generally higher improvement of these students who had the skills to formulate research questions and to plan experiments below the average level was found. The questioning skill developed in the first group 1.54 points and in the second group 0.32 out of 12 points (t=4.28, p<0.01), while the planning skill improved in the first group 4.83 points and in the second group 1.31 points out of 18 points (t=7.51, p<0.01). Next, we discovered an influence of the types of structure and support of worksheets on the group with higher pre-skills in the case of planning skill (n=183). It encouraged us to find a hierarchical system of supportive elements.

The results of the ANCOVA analysis demonstrated that apart from the generally higher improvement of the planning skills in the group that used the second worksheet, the first worksheet developed students’ planning skills more among those, whose initial planning skills were above an average (F=16.77, p<0.01). The students’ gender and initial skills were used as covariates in this case as well. This proved our hypothesis about the appropriateness of different types of worksheets on the learners with diverse level of initial skills. The open-ended approach in developing students’ planning skills is effective only if they have a higher level planning skill. The students with a lower level initial planning skill will improve more if they are provided with a “recipe” that is supported with guiding questions.

Conclusions

We applied different types of supportive elements on inquiry worksheets for using two computer-based models about the balance of an ecosystem and the air pollution in forests. These elements were the examples and guiding questions in formulating research questions or hypotheses and the “recipe” of tasks and guiding questions

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for supporting the process of planning experiments. The current results have demonstrated that all supportive elements in the structure of the worksheets have a positive effect on the learning outcome. Both domain-specific knowledge and inquiry skills developed statistically significantly. However, significant differences between the effects on different groups of students were found.

Our first conclusion is related to the development of skills to formulate research questions and hypotheses. The results show that the development of the hypothesizing skill depends on the skill of questioning. In the current study, students had a low initial level of skills to formulate research questions and, therefore, the skill to formulate hypotheses did not improve statistically significantly. A practical implication of this finding is that there is a need to assess students’ pre-skills and to provide them with tasks according to these. Questioning is a simpler task compared with hypothesizing because it can be regarded to the basic process skills but hypothesizing is certainly an integrated skill and, therefore, the focus have to be set on developing this skill in a case of novices while the hypothesizing has to be the focused activity if the target group is formed from experts.

The second conclusion concerns the appropriateness of different types of inquiry worksheets for developing students’ skills. The findings of the current study demonstrate that the students are more successful if they are firstly provided with open ended questions for formulating research questions and, next, with a list of hypotheses. That type of structure supports them in activating domain-specific pre-knowledge and in developing their initial ideas about the problems. The development of the students’ questioning skills was significantly better compared with the group that was provided with a list of examples already in the beginning of the learning process.

The last conclusion shows how the skill of planning has to be improved effectively. Our study demonstrates that the appropriate supportive elements mainly depend on the students’ pre-skills. The students with a lower initial planning skill have to be provided with a “recipe” of the experiment that has to be analyzed step by step. The others with a higher level initial planning skill will benefit more from guiding questions that help them in designing a particular experiment.

It can be also concluded that computer-based models with appropriate structure of students’ worksheets can be used effectively for developing inquiry skills related to the hypothesis space and also for acquiring domain-specific knowledge. However, the level of students’ improvement depends on their individual characteristics that have to be taken into account in providing them with appropriate type of worksheets containing different supportive elements in their structure.

References


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