When Students Benefit from Analyzing Their Inquiry

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Abstract. There is a need to find out how to enhance the effect of a generally successful inquiry approach in schools. In our study, we hypothesized that supporting students' reflection could have a positive effect on their general inquiry knowledge, transformative inquiry skills, and domain-related knowledge. A scenario-based complex technology-enhanced learning environment called Science Created by You was used by 54 students (age, 14–18 years). The results demonstrated that students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge all improved statistically significantly; however, no changes were found in reflective activities—in analyzing inquiry, in assessing the value of analysis, and in considering alternative solutions. Indeed, students' domain-related skills were associated with reflection. The students with a higher level of knowledge analyzed their inquiry more often, and they considered more often alternative solutions of inquiry. No associations were found between domain-related knowledge and inquiry knowledge or skills.

Keywords: domain knowledge, inquiry learning, reflection, technology-enhanced learning environments.

1 Introduction

Inquiry learning is more effective than many other "traditional" learning approaches. Alfieri, Brooks, Aldrich, and Tenenbaum [1] have demonstrated in a meta-analysis that inquiry has a mean effect size of 0.30 against other forms of instruction (e.g., direct instruction or unassisted discovery). Furtak, Seidel, Iverson, and Briggs [2] found in their meta-analysis that the effect size could even be 0.50 in favor of the inquiry approach over traditional instruction. However, despite the proven value of inquiry, it is not often widely applied in schools, and therefore, there is a need to find out how to enhance the role of inquiry in teachers' everyday practice.

In our study, we hypothesized that supporting students' reflection in a complex technology-enhanced learning environment could have a positive effect on their general inquiry knowledge [3], transformative inquiry skills [4], and domain-related knowledge. If it would be so, then it is an important sign to the teacher to apply inquiry more often.

Reflection is a cognitive process of learning from the learner's own experience [5], and it supports students in analyzing their learning experience in order to change their

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behavior during the learning process or restructuring of knowledge structures if needed. In the context of science education, it is important that reflection could support inconsistencies between the student's initial understanding and scientific explanations [6]. However, the associations could even be two-directional. Baird and White [7] and Davis [8] showed that inquiry learning also improves reflection skills.

In order to find the relations between the level and improvement of reflective activities, general inquiry knowledge, transformative inquiry skills, and domain-related knowledge, a specific study was conducted in the SCY-Lab using a "learning mission" in ecology. SCY-Lab (`http://www.scy-net.eu/`) is a technology-enhanced learning environment designed for design-based inquiry learning through creating "products" [9,10]. Three research questions were formulated:

1. To what extent do students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge improve in using the complex technology-enhanced learning environment SCY-Lab?
2. What kind of changes appear in students' reflective activities if they practice reflection during inquiry in the SCY-Lab?
3. How can the level of reflective activities be associated with students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge?

2 Methods

Four voluntary teachers from four different schools asked their students (age, 14–18 years) to participate in the study. They all had to fill in a prequestionnaire and post-questionnaire that contained four parts. First, students' general inquiry knowledge was evaluated by two types of questions: students had to sequence the stages of inquiry and to explain why each of the stages is important in the inquiry process. Second, students had to formulate two research questions, hypotheses, and inferences. Research questions and hypotheses were formed on the basis of a story, and inferences were made on the basis of a figure presenting results of a study. The level of general inquiry knowledge and transformative inquiry skills was assessed according to a scale developed by Pedaste and Sarapuu [11]. Third, students' domain-related knowledge was assessed by asking two open-ended questions about why an ecosystem needs light and what the importance of photosynthesis is (questions related to the topic discovered in the SCY-Lab). In both cases, every correct aspect mentioned in the student's answer increased the final score. Fourth, students' reflective activities were described through three questions: *How often did you analyze your learning process? How important is analysis of the inquiry process and why? Will you do something differently next time in the inquiry process, and what would it be?*

The learning process was conducted in a scenario-based complex technology-enhanced learning environment Science Created by You (SCY) [9]. In this learning environment, a complex "mission" of learning ecological principles was completed. On this "mission," students combined hands-on data collection and working in the

Internet-based SCY-Lab learning environment. In the SCY ECO mission, students are asked to solve four problems [10]. In the current study, they had to solve only the problem to discover the role of light in the level on photosynthesis. In their learning process, students formulated research questions and hypotheses, planned and conducted an experiment, collected and analyzed data, and made inferences in order to draw conclusions. During this process, they were asked to reflect their learning by asking supportive questions as suggested by Kori et al. [6] and Runnel et al. [12]. They were asked to discuss their experiences of the whole inquiry cycle, to describe limitations of their inferences, and to explain what in their learning process should be done next time in the same/different way.

Only results of the students who completed both prequestionnaires and postquestionnaires were included to the analysis of the current study. In the cases where some students did not complete all four parts of the questionnaire, only the incomplete parts were excluded. In total, 54 students were involved in the analyses. Students' improvement in general inquiry knowledge, transformative inquiry skills, and domain-related knowledge was analyzed by *t* test, whereas their answers were distributed normally. The changes in categorical variables about reflective activities (distribution of categories before and after intervention) were tested with chi-square tests that were also used for finding associations of reflective activities with the level and changes of inquiry knowledge, inquiry skills, and domain-related knowledge. In this case, median split was used to differentiate the students who had a higher or lower level or change in knowledge or skills in comparison with the median.

3 Results and Discussion

According to the first research question of the study, students' improvement in general inquiry knowledge, transformative inquiry skills, and domain-related knowledge was clarified. *t* test results showed that all these improved statistically significantly in using the technology-enhanced learning environment SCY-Lab and, in particular, the ECO mission (Table 1).

Table 1. Comparison of students' general inquiry knowledge, transformative inquiry skills, and domain-related knowledge in the prequestionnaires and postquestionnaires.

Knowledge/skill	Prequestionnaire		Postquestionnaire		*t* test	*p*
(maximum score)	Mean	St. Dev.	Mean	St. Dev.		value
General inquiry knowledge (35)	27.3	3.8	30.3	2.9	−6.58	<0.01
Transformative inquiry skills (46)	24.6	9.4	30.6	8.2	−8.27	<0.01
Domain-related knowledge (8)	2.6	1.4	3.5	1.4	−6.35	<0.01

No statistically significant changes were found in students' reflective activities as a result of using SCY-Lab. Thus, the answer to the second research question is that learning in SCY-Lab does not initiate changes in students' reflective activities. The reason for this could be that reflection skills were not specifically supported in the learning environment. Reflective questions only guided students in analyzing their inquiry process. However, it was still possible to discover how reflective activities could be associated with students' knowledge and skills.

Our third research question was about the relations between the level of reflection activities, knowledge, and skills. The outcomes of chi-square analysis showed that the characteristics of reflection do not associate statistically significantly with the general inquiry knowledge and transformative inquiry skills. However, interesting associations were found with domain-related knowledge. The students who had lower knowledge gain would do something differently next time in the inquiry process ($\chi^2 = 4.4$, $p < 0.05$). It could show that reflective activities guided students toward understanding about their difficulties—if their knowledge gain was lower than average, then they started to think with higher probability on alternative approaches for learning.

It was also found that the students with a higher level of domain-related knowledge are more often analyzing their inquiry activities (in prequestionnaire, $\chi^2 = 7.8$, $p < 0.05$; in postquestionnaire, $\chi^2 = 5.8$, $p = 0.056$) and are most likely considering changes needed in their inquiry ($\chi^2 = 3.9$, $p < 0.05$). A possible explanation here is that a particular level of domain-related knowledge is needed in order to activate students' reflective thinking. This finding is in accordance with the studies of Pedaste and Sarapuu [13,14], who found that in acquiring problem solving skills in complex Web-based learning environments, students should be divided into groups and supported according to their personal needs in order to achieve maximum improvement. They detected five different groups, and two of them applied different learning strategies but were both successful without any support, whereas the three other groups all needed different types of cognitive or metacognitive support. In the context of supporting reflection for enhancing inquiry learning, further studies are needed to specify effective guidance strategies.

4 Conclusion

In the current study, we hypothesized that supporting students' reflection could have a positive effect on their general inquiry knowledge, transformative inquiry skills, and domain-related knowledge. However, we found that at least in complex technology-enhanced learning environments, such as the SCY-Lab, a higher level of reflection can be associated only with domain-related knowledge, but not with general inquiry knowledge or transformative inquiry skills. This finding is important in designing learning processes and students' support in complex learning environments. According to our findings, we recommend first to focus on developing reflection skills in the context of gaining domain-related knowledge. The students with a higher level of knowledge in pretests and posttests analyzed their inquiry more often than the others, and the students with a higher level of domain-related knowledge in the end of the learning processes considered more often alternative solutions of inquiry. However, even in this case, the students with a higher level of domain-related knowledge will benefit more. It could be hypothesized that students' general inquiry knowledge and transformative inquiry skills would be enhanced in use of reflection more if the reflective skills and domain-related knowledge are already improved to a specific level. This would be an interesting topic of further studies.

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