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ACTION RESEARCH TO STUDY PROBLEM SOLVING SKILLS OF PRIMARY SCHOOL PHYSICS STUDENTS

Jörgen Ivar Sikk and Kairit Tammets[1]
Tallinn University, Narva mnt 25, 10120 Tallinn, Estonia
[1]Senior Researcher

ABSTRACT

PISA studies have concluded that while the level of knowledge, amongst students in Estonia, is good the level of higher order thinking skills is lower, especially in natural sciences, which is accompanied by lower study motivation. In order to study the level of higher order thinking skills and what influences those skills, an action research was conducted. The research was done in Tallinn 21. school with 90 students from 8th grade. The students studied, using ICT enhanced study material specifically made to increase their higher order thinking skills. In order to study the effects of the study material, student's problem solving skills were measured before and after using the new study material. Also, the students had to answer a questionnaire, which was measuring their study motivation and self-confidence. The research concluded that the study material has an effect on the level of higher order thinking skills, but the statistical evidence was lacking to clearly understand the role of the new study material.

KEYWORDS

Action Research, Problem Solving Skills, ICT Learning Materials

1. INTRODUCTION

Estonia's success in the PISA tests is the fruit of the cooperation, to which parents, school leaders and teachers have contributed. Despite the good results, student struggle with higher order thinking skills (Schleicher, 2018), a result which was already hinted at in the 2006 PISA tests. Developing of higher order thinking skills are supported by activating and research-based learning methodologies (Rohatgi, et al., 2016). Although teachers are aware of these methodologies in Estonia (Kikas, E., 2015; Henno, et al. 2017), they are rarely applied in class (Schleicher, 2018; Le Donne, et al., 2018), especially in natural sciences (Henno, et al., 2017).

However, higher cognitive thinking skills need to be addressed in order for students to cope in the information age. In addition to reading, arithmetic, and writing, students must be able to think critically, solve problems, communicate, and collaborate, and they must acquire skills that will ensure their ability to learn and retrain in the future (Johnson, P., 2011). To this end, it is important to use information and communication tools (ICT), as the ability to use these tools will continue to be important, and they have certain advantages over traditional learning materials (Genlott & Grönlund 2016; Jolliffe, et al., 2001). Learning materials created with ICT tools and the methods applied through them have shown advantages over other tools in the development of higher order thinking skills and more precisely in problem-solving skills (Heikkilä & Lonka, 2006). Although ICT-based tools have an advantage, there are also problems (Genlott and Grönlund, 2016; Lndblom-Ylänne & Lonka, 1999) and because the development of higher order thinking skills also depends on the subject context (Shabrina & Kuswanto, 2018), one should take a lot of care when creating teaching materials addressing those skills.

Due to the relative lack of focus on higher order thinking skills in natural sciences, this action research focused on improving them, through teacher curated study materials. The following research questions were posed: 1) Which kind of higher order thinking skills are necessary in the context of natural sciences? 2) How to evaluate student's higher order thinking skills? 3) What is the effect of created study-material on student's higher order thinking skills?

2. LITERATURE REVIEW

2.1 Higher Order Thinking Skills

Higher Order Thinking Skills (HOTS) go beyond basic observation of facts and memorization and can be considered to be the more demanding cognitive skills of Bloom's Taxonomy, such as Analysis, Synthesis and Evaluation (Krathwohl & Anderson, 2001). Concepts of critical thinking, problem solving skills and creative thinking are also included as HOTS and, in general, the concept has a wide variety of sub-contexts and overlaps (Brookhart, 2010). Despite the plurality, all the HOTS depend on the context they are applied to, which means that developing HOTS requires also the understanding of contextual space (Zohar, 1996). In the current study the focus was set on metacognitive, problem solving and critical thinking improvement., because they are rarely applied in natural sciences (Henno, et al., 2017), but found important in strategic planning of education (Republic of Estonia, 2020). Metacognitive thinking requires the student to be involved in analyzing and regulating their learning process (Bransford et al., 1999) and thus is also an important part of HOTS. Metacognition develops the students capability of choosing the right means and strategies to overcome problems. As such, it is an important skill to have in modern times, due to everchanging skillset requirements and adaptation issues (Brinkley, 2019). Moreover students with higher metacognitive skills tend to be better at guiding their studies (Rohatgi, et al., 2006), finding better strategies in order to solve problems (Herawaty, et al., 2018) and over all be more involved in the studying process (Rohatgi, et al., 2016; Desoete, et al., 2019). Although further research is needed to understand the carry-over effect of metacognitive skills in various disciplines (Tanner, 2017).

Tied together with metacognitive skills are problem solving and critical thinking skills, which have gotten a lot of attention from researchers. Problem solving skills have strong ties with Bloom's "Analysis" and "Evaluation" categories (Krathwohl & Anderson, 2001), while critical thinking is more-so a process of evaluating strategies in order to find the best solution to a problem (Bransford, et al., 1999).

2.2 Fostering the Development of HOTS and Problem Solving Skills

In order to hone and develop those skills cognitively activating strategies and supporting of metacognitive processes should be applied (Snyder & Snyder, 2008). Such strategies do exist already and mainly fall under constructivist or cognitive teaching methods, where the teacher is more supporting the process of learning, and to a lesser extent leading it (Le Donne, et al., 2016). Methodologies like flipped classroom can give students practical problem solving and critical thinking skills, even if the teacher themselves is not so familiar with it (Smith, et al., 2018), or guided group work (Fung, 2017). Such inclusive methodologies also affect problem solving capabilities of students (Lin, et al., 2014), additionally it can bring better results in terms of activating the students (Lonka & Ahola, 1995), while depending on the teachers readiness for that way of teaching (Henno, et al., 2017).

The inclusion of ICT capabilities, especially one's that students are familiar with (like smart phones), tend to have a positive effect on the students critical thinking (Ismail, et al., 2018). That familiarity can also allow students easier means of self-reflection, which, as a metacognitive skill, can aid in building problem solving skills (Kim & Kim, 2019). An important aspect of online environments is their plurality, in which games (Lin, et al., 2014), interactive simulations (Ceberio, et al., 2016) and other visual media are all capable of enhancing the learners absorption of information and skills. While this study focuses on problem solving, it is important to note the „across the board" positive effect of ICT on the development of higher order thinking skills and its sub theories. One interested in developing learning materials for it, should not leave these tools unnoticed.

As mentioned, the improvement of problem solving skills demands a closer look at the learning materials, since the learning materials create the context, and context influences HOTS (Zohar, 1996) and thus problem solving skills. While previously discussed ICT environments can help in improving the students problem solving skills the learning materials should create a helping narrative for it. More precisely the narratives should be engaging by being actual and pose interesting questions (Dori, et al., 2003). For lack of a better word they should introduce a problem, which is easily relatable. Although a more simple worksheet can also be feasible (Verdina & Sulastri, 2018), or the narrative doesn't have to be text based at all (Lin, et al., 2014). What ever the form of narrative, it will drive the meaningful acquirement of information and help the student

in their self-guided learning (Sanchez-Marti, et al., 2018). The use of ICT should have some advantages over classical study materials (Jolliffe, et al., 2001; Genlott & Grönlund, 2016), both in audio-visual information and also from the point of student engagement (Hakkarainen, 2000; Genlott and Grönlund, 2016).

In conclusion, the learning material's context and narrative should be intertwined to create an engaging and reflective learning process for the student, while also employing visual and active media, through ICT to help achieve needed learning goals.

3. METHODOLOGY

3.1 Research Design

In order to research the effects of ICT enhanced study materials on student's problem solving skills an action research in an Estonian elementary school was conducted during a period of one month in spring of 2020. The experiment was done in physics class, since in that curricula constructivist practices are seldom used and tend to not include the development of higher order thinking skills, at least in Estonia (Henno, et al., 2015). The study included 90 students from 8th grade (age 14-15). The students were divided randomly to groups of three and each group was assigned, at random, a study material. There were three types of study materials:

1) ICT enhanced problem solving skill focused study material
2) ICT enhanced classical study material
3) Classical study material

The purpose of the new study material (Group 1) was to develop the student's problem solving skills, while also following the criteria of national curriculum. The study material follows the recommendations of Broadbear (2003) and McMahon's (2009) to increase the cohesion between subject context and developing problem solving skills. Amongst exercises are also metacognitive reflective parts, which followed the structure and recommendation of Tanner (2017), Herawaty (2018) and Desoete, et al., (2019). The exercises sometimes lacked a clear definitive answer, and as such demanded more analytical and comparative approach. Such strategy is important when developing critical thinking and problem solving skills, since one should be able to choose between and evaluate different viable strategies (Bransford, et al., 1991). Additionally, students had to find the right information in situations where there was too much extra information, or the important information was given in a non-standard way, in an attempt to foster engagement (Dori, et al., 2003). Included were guiding comments by the teacher, never revealing the answer, but encouraging to look for help or guide the thought process. Moreover, a curated choice of simulations and other visual-media was added to the study material to help with visualizing the physics problem and finding the correct solution, since there is additional benefit of using ICT to engage students (Masiello, et al., 2005; Ismail, et al., 2018; Lin, et al., 2014; Ceberio, et al., 2016).

The ICT enhanced classical study material (Group 2) is an online environment developed by a publisher in Estonia, who is also responsible for writing the work- and study books for general schools. The environment (opiq.ee) has the same structure and exercises as their books, with the added benefit of integrated videos and interactive exercises. The classical study materials (Group 3) are the official work- and study books that are used in physics classes all over Estonia. In physics their structure is the same for every topic. The student is given the theory and definitions, then a few examples and in the end some exercises. Exercises are mostly focused on physics formulas, with few experiments and team-orientated problems.

Comparing results from the first two groups should give an idea on the effect of ICT on problem solving skills. The third group is a control group, in which the students use their already familiar study books and exercises there-in.

Action research in education can also be called teacher research (Manfra, 2019), due to its ulterior motive being to improve the teachers teaching capabilities. In this research the teachers role consisted of a) following the process of student groups, b) evaluating the group work and c) giving live feedback to student's if they were struggling with semantical or group related issues. Due to COVID-19 restrictions, the student's conducted the work online and the live feedback part of the role was somewhat weaker than initially planned, but later, when classes resumed an open forum way of discussing the study material and its impact was done. Due to it the wording of evaluative tests was changed. Additionally, further changes were made to the study material based on student feedback, but since the current research paper focuses on the results of the first round of testing, then the changes aren't included in this paper.

3.2 Procedure and Data Collection

Before using the study materials on a new topic, the student groups had to do a pre-test to determine their level of problem solving skills. The pre-test was made in the context of the curriculum that they had already gone through, so the physics theory and formulas were already familiar. But, unlike their usual physics tests this one focused on problem solving skills and metacognitive aspects. The pre-test was made following examples from 2006 PISA test and research papers that have evaluated problem solving skills before (Whiley, et al., 2017; Snyder & Snyder, 2008). The test consisted of four exercises each one being gradually more complex.

After the pre-test, students in their groups of three were tasked to study for a new topic, using the materials and procedures given by the teacher (the materials mentioned before in this paper). Due to COVID-19 regulations the classes were online and the students had to organize their group work by themselves. The teachers role was to make sure the group work was happening and every person was involved. The groups had one week to use the study materials.

The post-test was to measure the student's problem solving skills and was identical in structure to the pre-test. The difference being that the context was reflecting the new physics topic. The post-test was to give an idea on the change (or lack of) of students' problem solving skills after using the study materials.

The qualitative data gathered from the pre-, and post-tests were analyzed using standardized evaluation of Estonian physics exercises and following the example of Karatas & Baki (2013), in which problem solving skills are evaluated in phases. Only student groups who completed both problem-solving tests and finished the study materials were included in the analysis (27 student groups out of 30). Since there were three different distinct groups then in the analysis we use the following abbreviations:

A) VIII.1 - Student groups who used ICT enhanced HOTS focused study material;
B) VIII.2 - Student groups who used ICT enhanced classical study materials;
C) VIII.3 - Student groups who used classical study materials.

4. RESULTS

4.1 Problem Solving Pre-Test

The problem solving pre-test was evaluating student's current level of higher order thinking skills in the context of physics class that they were already familiar with. On average the different student groups performed quite similarly on the pre-test (VIII.1 – 45%; VIII.2 – 51%; VIII.3 – 43%). After doing an ANOVA test on the pre-test results, we found that the results were statistically insignificant (Sig. 0.81; F – 0.212, df = 2), meaning the difference in scores wasn't due to the assigned group.

Table 1. Problem solving skills pre-test results of different study material groups in the context of exercises

	Problem solving skills test 1		
	VIII.1 (%)	VIII.2 (%)	VIII.3 (%)
Exercise 1	75	75	45
Exercise 2	55	85	45
Exercise 3	46	60	57
Exercise 4	35	28	30

The text questions were numbered based on their relative difficulty level, Exercise 1 being easier than Exercise 2 and so on. The results were more similar between VIII.1 and VIII.2, with VIII.3 showing, relative to others, lower average.

4.2 Problem Solving Post-Test

The problem solving post-test results differed significantly from the pre-test ones. VIII.1 group average score was 77%: VIII.2 group average score 60% and VIII.3 group's average was 18%. ANOVA test showed that the assigned group did have an effect on the test scores (Sig. = 0.0001, α = 0.016) and that approximately 46% of the dispersion in results was due to it (η_p^2= 0.461).

When looking at the data from the point of view of individual exercises then we see the relative progress of groups VIII.1 and VIII.2 to group VIII.3. The biggest difference between the groups being the most complex exercise 4.

The post-test score was statistically significant (df = 2, F – 23.157, Sig. 0.00001), but when making a two tailed T-test we see that the difference between VIII.1 and VIII.2 isn't.

Table 2. T-test of groups' post-test results. df = 2, F - 23.157

Groups	P(T<=t) two-tail	α	Significant
VIII.1 and VIII.2	0.0616	0.0160	No
VIII.1 and VIII.3	4.57E-05	0.0160	Yes
VIII.2 and VIII.3	0.0011	0.0160	Yes

Table 3. Problem solving skills post-test results of different study material groups in the context of exercises

	Problem solving skills test 2		
	VIII.1 (%)	VIII.2 (%)	VIII.3 (%)
Exercise 1	100	90	20
Exercise 2	70	50	15
Exercise 3	55	62	10
Exercise 4	70	49	20

5. DISCUSSION

While the pre-test showed quite similar results across the board, the post-test showed a significant shift. The group VIII.1, who received the new ICT enhanced study material improved their results significantly, while the results of VIII.2 showed minor improvement and the group VIII.3 results showed a steep decline. The main difference between the groups was the addition of ICT for groups VIII.1 and VIII.2 and another was the difference of study material (VIII.1 vs the rest). Considering that the t-test didn't show any statistical difference between VIII.1 and VIII.2 then one explanation could be that the inclusion of ICT capabilities and their quality plays a role in developing higher order thinking skills. More so, due to there being no statistically important difference between VIII.1 and VIII.2, even though the former deployed a HOTS focused study material. Perhaps a bigger sample size should be used.

An important element of this group work was communication between group members. The novel study material of group VIII.1 was developed keeping that nuance in mind. That meant that the information and exercises required discussion amongst each member. The classical study material of VIII.3 is developed as a thorough theoretical work, meaning that it doesn't require the reader to make the connections themselves. As a study material it fosters passive learning and requires the student to think for themselves only at the end of the chapter in form of questions, and even then mostly checking the students lower order thinking skills. Such an approach is effective when we, as educators, are interested in relaying enough information with the least amount of time (and time is an important constraint in education). However, such material is lacking when we want the student to develop their higher order thinking skills.

There can be couple of reasons for the decline of VIII.3 group: a) usually their study material is used together with teacher instruction and b) they learned new information using study materials that don't incorporate higher order thinking skills as much. This would mean that, even though their problem solving test results declined it didn't happen because their problem solving skills declined, but that their weak

contextual knowledge didn't allow their higher order thinking skills to be applied. Further evidence of that is shown with the results of Exercise 3, where the students had to find the right answer from with-in the text (thus using their functional reading skills and making generalisations), which in turn requires a good grasp on the theory, and as such is quite unusual for a physics problem (which classically require an application of a formula). Considering that a person's functional reading ability doesn't change rapidly then we can guess that the decline in the results of Exercise 3 means that the students lacked generalisation ability in the context of that physics topic. An important distinction is that groups VIII.1 and VIII.2 used different ICT environments and capabilities, and as such definite conclusions on the effects of ICT on study motivation is hard to draw is in this study. Additionally group VIII.2 used an ICT environment that was already familiar for them, while group VIII.1 used novel environments. Considering that time spent in an online study environment has a positive effect on the study results (McMahon, 2009) then it is even harder to evaluate the true connection between ICT and study motivation in this research.

6. CONCLUSION

Problem solving skills are important tools, which should be taught to students, while also considering the context of curriculum. However, the attention these skills receive, is lacking (Henno, et al., 2015). The current action research aimed to alleviate this issue by creating study materials, which could be used in a standard natural science class, with all its time and curriculum constraints. The study material aimed to be engaging by offering various ICT-enhanced aids and was built on a narrative. The study material was compared with other study materials to evaluate the effect of it on students' problem solving skills. The results showed that while the study material does have an effect on problem solving skills it is difficult distinguish the difference between ICT enhanced study material and ICT enhanced problem solving skills study material. Further research should be conducted, and, for statistical assurance, number of study groups should be increased. Nevertheless, the role of study materials remains an important part of developing student's (higher order thinking) skills, maybe even more so with the advances in ICT technology and its ease-of-use.

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