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Mobile Based Inquiry Learning Application for Experiment Planning in the 8th Grade Chemistry Classroom

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Abstract: Although inquiry-based learning has been used in science classrooms for some time, students still have low inquiry skills, especially when it comes to formulating hypotheses and research questions and planning experiments. Taking stock of a growing number of mobile devices in schools and many advantages offered by mobile learning, we tried to solve the problem with the help of mobile learning. We developed a mobile based inquiry learning application which can be used as part of the chemistry lesson where students have to plan chemistry experiments. The application was tested in an 8th grade chemistry lesson with 22 students. Pre- and post-test showed no significant change in students' experiment planning scores because we only used the tool in one lesson; however, data collected by a questionnaire on feedback and potential usefulness of the tool according to the UTAUT model and conducted interviews confirmed that the application was easy to use and has potential in learning chemistry. Students and their teacher saw many benefits of the application, such as chance for individual learning, immediate and individual feedback and ease of use. According to our study, the application works well on both individual and collaborative learning scenarios. Observations confirmed that the application was easy to use and students had positive emotions while using it. In order to further test the application and get more data, a larger sample is needed for testing. Using the application in a longer period of time is also suggested.

Keywords: Inquiry-based learning, mobile learning, experiment planning, chemistry

1. Introduction

Inquiry-based instruction has been recommended as one of the best teaching approaches for the science classroom (DeBoer, 1991). According to Pedaste et al. (2015), the common inquiry cycle used in classrooms consists of five steps: orientation, conceptualization (where students develop research questions and hypotheses, investigation (planning and conducting an experiment or exploration), making conclusions, and discussion. The last one, discussion, should run parallel to the other four phases and support them – there should be constant communication between students and reflection on the learning process in order to learn skills that could be transferred to new learning situations or real life. Since it is already a well-known teaching method, it is being used in school practice. However, the research conducted in Estonian schools shows that students still struggle with their inquiry skills – the poorest results are shown when formulating hypotheses and research questions and also when planning experiments (Pedaste et al., 2017a).

As planning and conducting inquiry-based learning can be time-consuming and often difficult for teachers, we argue that it may be reasonable to use the help of technology – to give teachers a tool for using students' or schools' devices in learning in a way that would improve students' inquiry skills. Using mobile devices in learning processes is nothing new in the current day and age, since mobile learning offers many advantages. The positive sides of using mobile devices in learning are flexibility, portability, convenience, access to information, attractiveness (Hashemi, Azizinezhad, Najafi, & Nesari, 2011), offering immediate feedback and challenge (Ciampa & Gallagher, 2013).

Although there have been many successful attempts to include mobile devices in learning activities (Suárez, Specht, Prinsen, Kalz, & Ternier, 2018; Sung, Chang, & Liu, 2016), not many effective mobile inquiry based learning scenarios have been offered to teachers. Moreover, research conducted in Estonian schools has shown that only about 5% of sixth and ninth grade students actively use mobile devices in the learning process in science and mathematics for different purposes such as collecting and sharing information, communication, and content-creation (Pedaste et al., 2017b), which is surprising, as the number of mobile phones in schools has been increasing for years.

Taking into account all the above, it is reasonable to find out if a mobile based inquiry learning application can be created in a way that can help to improve students' inquiry skills. Moreover, according to the authors' knowledge, there are no mobile applications which focus on experiment planning stage of the inquiry learning process.

Since discussion is an important part of inquiry-based learning, but, at the same time, there are no conclusive studies about the potential benefits of collaborative inquiry learning, it is reasonable to test the application in two settings: one device - one student; and one device - two students.

Based on the described problems, three goals were set in the current study:

1. Develop a mobile based inquiry learning application which helps students improve their skills in experiment planning.
2. Design an individual and collaborative learning scenario using the developed application.
3. Test the developed application in classroom settings.

More specifically, the following research questions were formulated:

1. How do students and their teachers describe the usability of the mobile based inquiry learning application?
2. How does the mobile based inquiry learning application improve students' experiment planning skill?
3. Is the mobile based inquiry learning application optimal for individual or collaborative usage?

2. Methods

Development of the mobile based inquiry learning application

The topic for the application was selected based on the assessment of students' inquiry skills in a national testing. According to this, planning of experiments was selected because it appeared to be one of the most difficult skills for students (Pedaste et al., 2017a). Next, an experienced chemistry teacher (12 years of teaching experience) was involved in designing the application that would support acquiring knowledge in chemistry and specific experiment planning skills. The first author of this article and the expert teacher designed a sketch and computational model of the application. Next, the model was introduced to a programmer and the technical solutions for implementing the computational model in an application were specified. Based on that, the programmer developed the application in an iterative process where the first author of the article was testing the application and asking for an expert opinion from the teacher when needed. In the process, several pedagogy experts from the University of Tartu were also involved.

Design of the study

In order to test the application, it was used in an 8th grade chemistry lesson at a secondary school in a small town of Estonia. 22 students at the age of 14 to 15 participated in the pilot study as part of their regular learning process. One teacher and one researcher were working with the students: the chemistry teacher had been teaching the class for four years, and the researcher had no previous contact with the participating students. First, the students filled in a pre-test evaluating their experiment planning skills. Next, the students followed a learning scenario and the researcher and the teacher observed it and helped the students where needed. After that, students filled in a post-test on experiment planning skills and a questionnaire to evaluate the learning application and its perceived effect on their learning. Finally, focus group interviews with the students were conducted to specify the gains of the learning process. In addition, an interview was done with the teacher to get an expert view on the application and the learning scenario.

Learning scenario

Students were given Android-based tablet computers and had to use an assignment for planning one experiment. The topic of the experiment was to study how the temperature affects the speed of the chemical reaction. In order to get the most beneficial results, the application was tested in two ways. Students were divided into two groups. In the first group, students were working individually with a device. In the second group, students were working in pairs with one device. Students were assigned to pairs according to their experience of using mobile devices in learning. These approaches were chosen because a study carried out in Estonian schools revealed that schools are sometimes unable to provide all students with individual mobile devices (Adov, Must, & Pedaste, 2017). Moreover, only about half of the students use mobile devices in learning activities, so it can be useful for students to work, for learning purposes, in pairs where one of the students is more experienced (Pedaste et al., 2017b). Proceeding from these ideas, the learning scenario used in the current study consisted of five phases:

1. Students were asked to form two equally sized groups based on their experience of using mobile devices in learning; next, seven pairs were formed so that each pair had one less experienced and one more experienced student; the rest of the students were assigned an individual learning scenario. In this way, a balance between less and more experienced users was achieved in the collaborative and individual learning scenarios.
2. A tablet computer was given to every student or pair and the mobile based inquiry learning application was introduced.
3. In the application, all students had to follow the assignment provided there (see the description of the application in section 3.1).
4. After using the application, all students completed a follow-up real experiment that they had just planned in the application (the final correct plans were the same for all students).
5. The learning phase finished with a short summary and debriefing by the teacher.

Pre- and post-test and a questionnaire

In order to test if the application helps students to more effectively plan an experiment in chemistry, pre- and post-tests were conducted by an experienced chemistry teacher and the researcher. The topic was the same as in the application, but the variables of the experiment were different. In the test there were two assignments – after reading the stated hypothesis, students were supposed to choose the relevant laboratory equipment and substances to test if the stated hypothesis is correct (Figure 1A). Second task was to choose the right sequence of the experiment steps (Figure 1B).

A

The claim: The higher the acid concentration, the better it reacts with the metal.

Select the appropriate experiment tools from the list to check the claim:

□ 10% HCl
□ Zn-granules
□ Cu-chips
□ 15% HCl
□ NaOH
□ Beaker
□ Dropper
□ Bunsen burner
□ Funnel
□ Test tubes
□ Test tube rack
□ SiO_2
□ 5% HCl

B

Put the experiment steps in the correct order, typing the correct sequence number before the stage.

_ Pour different concentrations of acid solutions into three test tubes.

_ Make conclusions. I check the validity of the hypothesis.

_ Follow the safety precautions.

_ Monitor the changes that occur (gas release intensity).

_ Put Zn-granules in three separate test tubes.

Figure 1: The sample items of the pre- and post-test.

Two tests were created, and for half of the students one was used as a pre-test and for the others the same was used as a post-test. In this way, comparability of the pre- and post-tests in the whole group was achieved. Moreover, the tests were composed with the help of the chemistry teacher to ensure that their level of difficulty was the same.

In both tests, students were able to score a maximum of 18 points. The questionnaire had 10 questions on a five-point Likert scale, following the relevant dimensions of the UTAUT model (Unified Theory of Acceptance and Use of Technology, Venkatesh et al., 2003) and addressing students' (1) perceived usefulness of the application (4 questions); (2) ease of use of the application (3 questions); and (3) availability of facilitating conditions for using the application (3 questions). The test items were selected from a validated instrument (Venkatesh et al., 2003) in discussion between the two authors and adapted for the current study. The Cronbach's alpha value of the questionnaire is .73 and between the values of .58-.63 in three separate measured dimensions. The tests and questionnaire were administered on paper.

Interviews

After using the application and carrying out the laboratory experiment (and the post-test), five short semi-structured focus group interviews with the students were conducted. The size of the group was decided based on the study-specific aims, which were to collect the opinions of each participant. The interviews were held right after the experiment in a vacant classroom in the same school. Necessary parental consent forms were handed out prior to the day of the experiment and collected beforehand. Groups were interviewed as follows:

1. Interview with 4 students from collaborative group (group 1).
2. Interview with 4 students from individual group (group 2).
3. Interview with 5 students from collaborative group (group 3).
4. Interview with 4 students from individual group (group 4).
5. Interview with 5 students from collaborative group (group 5).

All the students were asked questions about their opinion of the usefulness of the application and their ideas as to how the application would be more useful and appealing to them. In addition, students from the individual group were also asked whether they would have liked to work in a pair at some point of the assignment and which were the benefits of working alone. Students from the collaborative group were asked, accordingly, whether they would have liked to work individually at any part of the assignment and what were the benefits of working together with a peer on the assignment.

The questions of the semi-structured group interview were as follows:

1. How did you like the assignment?
2. What did you like about the application?
3. How would you improve the application?
4. Was the application easy to use?
5. Did the application give enough feedback on your answers?

Individual group:

6. Which benefits of working alone on an assignment do you see?
7. Would you have liked to work with a peer at some point of the assignment? Why?

Collaborative group:

8. Which benefits of working with a peer on an assignment do you see?
9. Would you have liked to work alone at some point of the assignment? Why?

With the interviews, information about the perceived effectiveness of the application and effectiveness of each learning scenario was collected.

In addition to interviews with students, a short semi-structured interview with the teacher was held. The teacher was asked the following questions:

1. What do you think did the children like the application?
2. Was the application easy to use for you?
3. How did the application help you carry out the lesson?
4. What did you like about the application?
5. What would you change in the application?
6. Do you think the application helps to improve experiment planning skills?

The interviews were conducted, recorded and transcribed by the first author of the study. The transcriptions were read several times in order to categorise the statements.

Observation

In order to validate the information collected from the interviews, participant observation was used during the learning process. Both the researcher and teacher were taking notes about students' emotions, indicators of ease of use of the application, difficulties during the assignment for planning the experiment in chemistry and other relevant information. The observation notes were discussed by both observers during which the conclusions were made.

Data analysis

The comparison of pre- and post-tests was made using the non-parametric Wilcoxon test, as the data was not normally distributed for several variables according to the Shapiro-Wilk test of normality. For the same reason, Mann-Whitney U test was used for comparing students who worked individually and those who worked in groups. Inductive content analysis was used to analyse the interviews and observations. SPSS Statistics version 25 was used.

In order to compare the attitude scores collected in the questionnaire formed according to the UTAUT model, the Wilcoxon Signed Ranks test was performed. Three factors were compared: four statements described the factor Perceived Usefulness; three statements described the factor Ease of Use; three statements described the factor Facilitating Conditions for using the application. One statement from the category Facilitating Conditions was formed as a negative statement, so the answers were reversed prior to the analysis. Answers to the questions were on a Likert scale and coded as 1 – totally agree, 2 – mostly agree, 3 – cannot say, 4 – mostly disagree, and 5 – totally disagree.

3. Results

Mobile based inquiry learning application

The application was developed in Android Studio and currently allows planning of seven experiments. Topics in the application are represented in the national chemistry curriculum.

In order to help students develop their skill of planning an experiment, the students are supposed to perform the following tasks: first, after clicking on the topic (which they are supposed to address in current chemistry lesson), students are instructed to read the description and stated hypothesis. Then, students are supposed to choose the relevant laboratory equipment and substances to test if the stated hypothesis is correct (Figure 2). After that, students can check their answers by pressing the button "check", and the application gives them feedback about their answer.

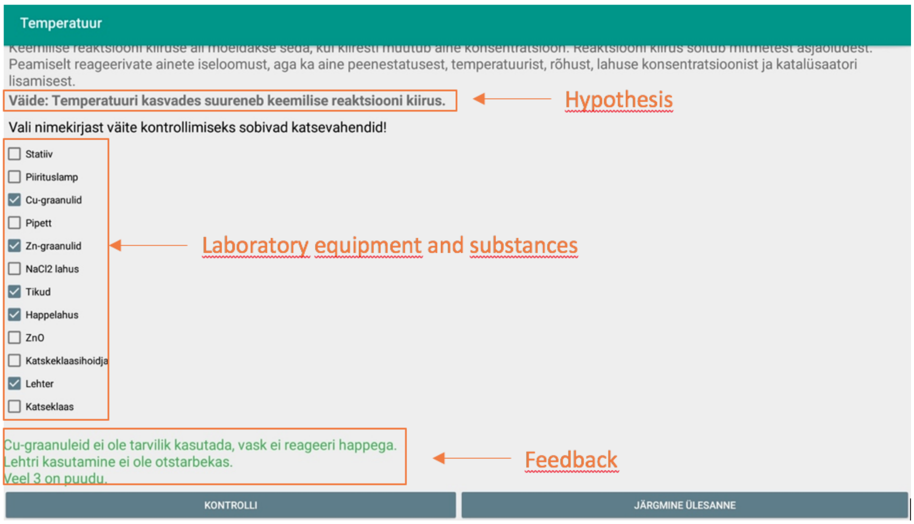

Figure 2. Screenshot of the first part of the assignment in the mobile based inquiry learning application.

For example, when a student chooses unnecessary laboratory equipment, the application gives him/her feedback that using the chosen equipment is not rational. Or, when a student chooses a chemical element which does not allow testing the correctness of the current hypothesis, the application gives the student corresponding feedback. Moreover, the application also tells the students how many boxes they have left to check. Students can advance to the next step when all the chosen equipment is correct. The next assignment for the students is to choose the right sequence of the experiment steps. Here, the application gives them simple feedback: whether the chosen sequence of steps is correct or incorrect (Figure 3). If correct, students can perform an experiment (or, depending on the teacher, watch the video of the experiment).

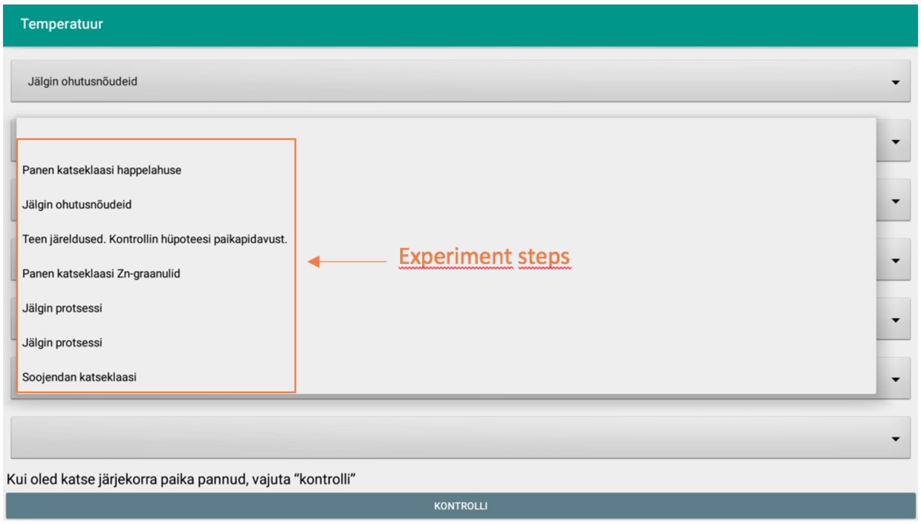

Figure 3. Screenshot of the second part of the assignment in the mobile based inquiry learning application.

Tests and questionnaires

The Wilcoxon signed-rank test showed that using the application once did not elicit a statistically significant change in students' test scores (Z = -0.74, p = 0.46). However, the mean value of the pre-test is slightly lower than the mean value of the post-test (14.82 and 15.32, respectively, standard deviation 2.11 and 2.30).

The analysis of the UTAUT model-based questionnaire results shows that the findings are quite positive. The mean rank of Perceived Usefulness is 2.68, for Ease of Use 1.73, and for Facilitating Conditions 1.59. Among these three attitudes, we found that perceived usefulness might be a slightly bigger issue than ease of use or facilitating conditions. To compare, we did a Wilcoxon test comparing students' perceived usefulness of the application, perceived ease of use of the application and perceived availability of facilitating conditions of the application. The results revealed a significant difference between ease of use and perceived usefulness ($Z = -3.24$, $p<0.01$) as well as between facilitating conditions and perceived usefulness ($Z = -3.45$, $p<0.01$).

Interviews

Interviews with the participating students took 7-10 minutes. Students were asked how they liked the assignment, what they liked about the application and if they would change anything about it. All the interviewed students brought out that the application was easy to use and the instructions were clear to them. Moreover, all shared the opinion that the feedback that the application gave was conclusive and helped them complete the assignment.

"The feedback was very good; otherwise we would not have known which answers were wrong." (Group 3)

"The application told you how many things you have left to pick, that was good." (Group 5)

Two students from different focus groups stated that they would have liked the application to have more pictures or animations. Other students in the groups agreed. For example, they brought out that the application could have pictures of laboratory equipment or animation of the following experiment. One student stated that she would have liked if, in addition to the chemical formula, there had also been the name of the substance.

In addition, student groups were asked about their thoughts about working individually and working with a partner during the assignment. Students who had been working in a pair stated that they liked working in a pair because they could discuss with their partner during the use of the application. As advantages of working together, they also pointed out the opportunity to get a second opinion about which laboratory equipment to use and to eliminate doubts.

"The other student also has an opinion, and you can ask if there is a need." (Group 1)

"Both of us talked about our ideas and we could discuss, so we could be sure." (Group 5)

According to their statements, they would not have wanted to work individually during the assignment, although one group agreed that they would have managed, since the assignment seemed easy to them. Students who were working individually felt that the advantages of not having a partner during the assignment were choosing their individual study pace, individual learning benefits and calmer working environment.

"I can concentrate better – nobody is talking next to me when I'm doing the assignment." (Group 2, example of calmer working environment)

"Sometimes when somebody is ready with the assignment in the classroom, they start to talk about it or the teacher gives us the answers. Here we could complete the task ourselves and see the results." (Group 2, example of choosing an individual study pace)

"When students are paired up and one student is really good at chemistry and the other is not, then the one who is good does all the work. Now we had to think ourselves." (Group 4, example of individual learning benefits)

"You will know what you know; nobody will tell you the answers." (Group 2, example of individual learning benefits)

Moreover, students who had worked individually were asked if, at any moment of the assignment, they had missed having a partner. All the interviewed students agreed that they had not.

The interview with the teacher took 13 minutes. In the interview, the teacher commented that in her opinion, the students enjoyed working with the application and were quite excited about it. The teacher found the application to be easy to use and brought out some advantages, such as individual feedback for students and the chance to choose their individual learning pace.

"I liked the feedback, which is also an important part of formative assessment. The student got individual feedback that he or she has made a mistake and that he or she can fix it." (Example of individual feedback to students)

"Sometimes in the lesson I cannot get to all the students. It (the application) gives quick and effective feedback and students can work at the pace they like, when they were ready they could proceed to conducting an experiment." (Example of individual learning pace)

The teacher also stated that the application can make finding students who are struggling easier for the teacher.

There were no suggestions how to change the application.

The teacher was also asked if the application can improve experiment planning skills. The teacher found that it can help students plan an experiment since the application makes them think before they proceed to the experiment.

"They (students) must think what the necessary steps are before they can perform an experiment. When you just give them substances and equipment, they might not think too hard."

The teacher also expressed excitement about the future use of the application and was curious about the next time it could be used in teaching. She suggested that the application would also be usable in students' own devices.

Observations

Observation notes were taken during the pilot study and focus group interviews. Students did not express negative emotions during working with the application. Most of the students who were working in pairs discussed the topic actively during the assignment. Students who were working individually did not talk to their desk mate. Three students had questions about what they should do after choosing the laboratory equipment because they failed to see the button "Next assignment". Neither the teacher nor the researcher recorded any other occasion where students needed help while working with the application. It took students 2-5 minutes to complete the assignment with the application. Some students who came to the teacher's desk to show their work seemed to be in a hurry to show that they had done the assignment correctly.

4. Discussion

In this study a mobile based inquiry learning application was created and tested in a classroom context. The application is based on previous findings: it allows students to choose necessary equipment and substances for a chemistry experiment and then lets them arrange the steps of an experiment. All the participants agreed that the application was easy to use and took a short time to learn. The teacher stated that the application would be helpful in the chemistry lesson since it lets the students choose their own study pace and get individual feedback, which is difficult to provide in a common classroom with many students. Both the teacher and the students evaluated the feedback that the application gave as sufficient and constructive. Previous studies researching mobile devices in classrooms have also concluded that feedback and individual learning options are advantages of using mobile devices in the classroom (Ciampa & Gallagher, 2013; Hashemi et al., 2011). Moreover, the application can be used in the students' own devices.

Although the analysed test results did not show a significant improvement in students' inquiry skills, we saw that the questionnaire and tests were suitable for measuring the outcomes of the pilot study. Lack of change in students' skills may be due to the short time of the piloting process, and the application might have a much stronger effect when used on a regular basis over a longer period of time. This conclusion is supported by previous studies, where longer intervention time has resulted in more significant effects on learning outcomes (e.g., see Ahmed & Parsons, 2013).

Results of the questionnaire indicated that students valued the application not only for being easy to use, but also for working well. They also considered the application to be rather useful to them, but the score of perceived usefulness was slightly lower. The reason behind it may be limited study time. It can be concluded that the usefulness of the application may also need more thorough investigation during future experiments. Perhaps some suggested elements should be added to the application in order for it to be more useful to learning, such as pictures of the laboratory equipment, animation of an experiment and full names of the chemical formulas. Adding pictures and animations in addition to text is also suggested in other e-learning studies, since they are appealing to students, help to learn and, in some cases, animations can help students see the phenomenon (in our case the chemistry experiment) from different or changing viewpoints (Clark & Mayer, 2011; Mayer & Anderson, 1992).

We did not, however, get solid evidence as to whether the application is more effective in an individual or collaborative learning process. The tests for assessing students' experimentation skills did not show any statistically significant differences in two groups. Results from interviews confirmed that the application is suitable for both learning scenarios, and as discussion is part of the inquiry learning process (Pedaste et al., 2015), we suggest that using both learning scenarios continues in future research in order to get more data.

Conclusions

A mobile based inquiry learning application focusing on experiment planning was created during this study. In order to get preliminary results on its effectiveness, it was tested in an 8th grade classroom with 22 students. Data from students was collected with a pre- and post-test, questionnaire, interviews and observation. Moreover, the participating teacher was also interviewed. The results indicate that the application is easy to use, offers a chance for individual learning and gives constructive feedback. Due to the short time of the pilot study, no significant changes were recorded in students' experiment planning skills. According to the tests and interviews, the application worked the same in both individual and collaborative learning scenarios. However, our study had some limitations, e.g., small sample, short learning time, only immediate but no delayed assessment of learning outcomes, and potential novelty effect. Therefore, in further studies the application should be used in a longer period of time in a wider sample in order to get more data on its effectiveness in improving students' inquiry skills.

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