Design and Evaluation of a Smart Device Science Lesson to Improve Students' Inquiry Skills

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Abstract. The prevalence of smart devices among young people is undeniably large, but concerns that they distract learning may be limiting their use in schools. In this study we demonstrate how tablet computers can be used effectively for teaching science. A digital biology lesson was designed in the Go-Lab environment and tested with 28 students (16–18 years old). Among the multiple tasks in the lesson, students had to search the internet for information, share digital data, formulate research questions and hypotheses using Go-Lab inquiry apps and interact with a virtual laboratory. Two conditions which differed only in the level of scaffolding provided by inquiry apps were studied. Results from pre- to posttest scores showed a statistically significant improvement in inquiry skills for students in both conditions. Overall, the findings suggest that an effective way to apply smart devices in science lessons is with digital materials that engage students in inquiry-based learning.

Keywords: Inquiry learning · Smart technology · Virtual laboratory · Inquiry cycle · Instructional design · Digital competence

1 Introduction

The prevalence of smart devices among young people today is undeniably large, but concerns that they distract learning may be limiting their use in schools. A survey of teacher views conducted with more than 2,000 middle and high school U.S. teachers found that 87% of respondents believed digital technologies were creating "an easily distracted generation with short attention spans," and 64% said digital technologies did "more to distract students than to help them academically." [1]. Nevertheless, the mobility of smart devices such as smartphones and tablets, their increasingly powerful computing capabilities and Wi-Fi access to the internet offer vast potential for learning—provided that meaningful classwork activities are created to engage the attention of students. Additionally, the responsible and educational use of smart devices in schools can support the development of students' digital competence, a general competence described, for example, by the DigComp framework as a set of knowledge, attitudes and skills needed by citizens to use digital technologies to achieve goals related to work,

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employability, learning, leisure, inclusion and/or participation in society [2]. However, a recent pilot survey of 6th and 9th grade Estonian students showed that although a majority may use smart devices very frequently for digitally competent activities, such as searching for information on the internet or communicating with others in digital environments, these activities occur primarily in contexts not related to school learning [3].

Especially important nowadays is to engage young people in science and mathematics. Success in today's technology-driven knowledge economy increasingly requires the types of skills students learn by studying these subjects. However, studies show that students in Europe [4], including Estonia [5], have low motivation towards learning science and mathematics. Changes in science instruction, along with new digital learning opportunities may offer better approaches to fostering positive attitudes among young people towards science and mathematics.

In the United States, the report *A Framework for K–12 Science Education*, describes a new approach to science instruction where more emphasis is placed on helping students engage in thinking and solving problems the way scientists do, and supporting students to better see how science is relevant to their lives [6]. More specifically, the framework advocates integrating three dimensions: (1) the *practices* by which scientists and engineers do their work; (2) the *crosscutting concepts* that apply across science disciplines; and (3) the *core ideas* in the disciplines. An emphasis on students actually "doing" the practices of science and engineering is further elaborated in the framework with eight key practices: (1) asking questions for science and defining problems for engineering; (2) developing and using models; (3) planning and carrying out investigations; (4) analyzing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations for science and designing solutions for engineering; (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information. These practices describe various inquiry skills that scientists and engineers apply when solving problems. Opportunities for young people to directly experience and apply these practices form the foundation of inquiry-based science education. A meta-analysis of active learning approaches in science education, overwhelmingly inquiry-based learning approaches, shows that such teaching methods are much more effective than traditional teaching approaches such as lecturing [7].

In Estonia, the importance of inquiry-based learning in science education has been recognized since 2011 in the National Curriculum at both the basic and secondary school levels. More recently, revised national science exams for 4th and 7th grade Estonian students now specifically assess inquiry skills such as formulating research questions and/or hypotheses; analyzing natural objects, phenomena and processes and explaining the cause-and-effect connections between them; planning experiments; and drawing conclusions from scientific data [8].

Research shows that inquiry-based learning can be enhanced through the use of computer simulations [9, 10]. Numerous interactive computer simulations for teaching and learning science can be found for free on the internet (see e.g., The PhET project at https://phet.colorado.edu). Interactive science simulations, such as virtual laboratories, offer the opportunity for students to learn by manipulating variables to discover cause-and-effect relationships, much like scientists might do when investigating unknown phenomena for the first time. However, students often struggle with inquiry tasks and consequently the effectiveness of technology-enhanced inquiry learning requires inquiry processes to be structured and scaffolded [9].

The Go-Lab (Global Online Science Labs for Inquiry Learning at School) environment is an online open educational resource that allows interactive science simulations to be integrated in structured and scaffolded digital learning spaces [11]. After a simulation is integrated in a Go-Lab learning space the space can be further enhanced by adding text, embedding multimedia content (images, videos, HTML5 elements), and adding Go-Lab learning applications (apps). All of these resources together constitute what is called an inquiry learning space (ILS). An ILS contains all the resources and tasks to engage students in inquiry-based learning.

The usual lesson plan of a Go-Lab ILS is based on the inquiry cycle framework of Pedaste et al. (2015) in which five general inquiry phases are identified: orientation, conceptualization, investigation, conclusion and discussion [12]. In each of these inquiry phases it is possible to provide students with guidance to address difficulties they may have with completing specific inquiry processes [13]. The conceptualization inquiry phase, in which students state theory-based questions and/or hypotheses, can be especially difficult for students.

In this study we designed a Go-Lab ILS for students to complete in their regular classroom while using their school's tablet computers. The learning effects of two conditions of scaffolding in the conceptualization inquiry phase were studied. The aim of the study was to evaluate the effectiveness of the ILS during classroom implementation in terms of changes in students' inquiry skills. In particular, the main research question was, "How to design an inquiry lesson in a technology-enhanced learning environment featuring virtual experiments and working on smart devices to facilitate the improvement of students' inquiry skills?"

2 Method

A biology teacher from a public secondary school in Estonia agreed to implement the Go-Lab intervention in his class during a regular 75 min lesson. A total of 28 students (6 boys, 22 girls) having a mean age of 17.0 ($SD = .74$) participated in the intervention. Students used their school's tablet computers (including a keyboard dock) and worked in groups of 3 to 5 persons to complete the digital lesson. A researcher was present to make observations as well as answer (technical) questions if necessary.

A virtual laboratory from the Virtual Biology Lab Project called *Sexual Selection in Guppies* (see http://virtualbiologylab.org/selection/) was selected as the computer simulation of interest. This simulation allows students to recreate the classic experiments performed by the biologist John Endler when he first investigated the balance of natural and sexual selection in guppy fish in the 1970s. Originally this virtual laboratory was created as a Java applet, but in order to make it compatible with smart devices, we created a new HTML5 version of it for use in this study (see Fig. 1 for a visual comparison of the two simulations).

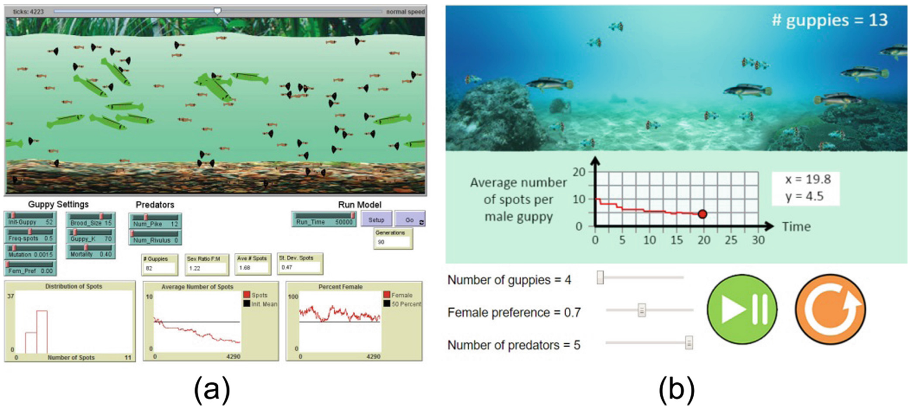

Fig. 1. Screenshots of the Sexual Selection in Guppies virtual laboratory: (a) the original Java applet version at http://virtualbiologylab.org/selection, (b) the redesigned smart device compatible version (http://leosiiman.neocities.org/guppy/GuppyLab.html).

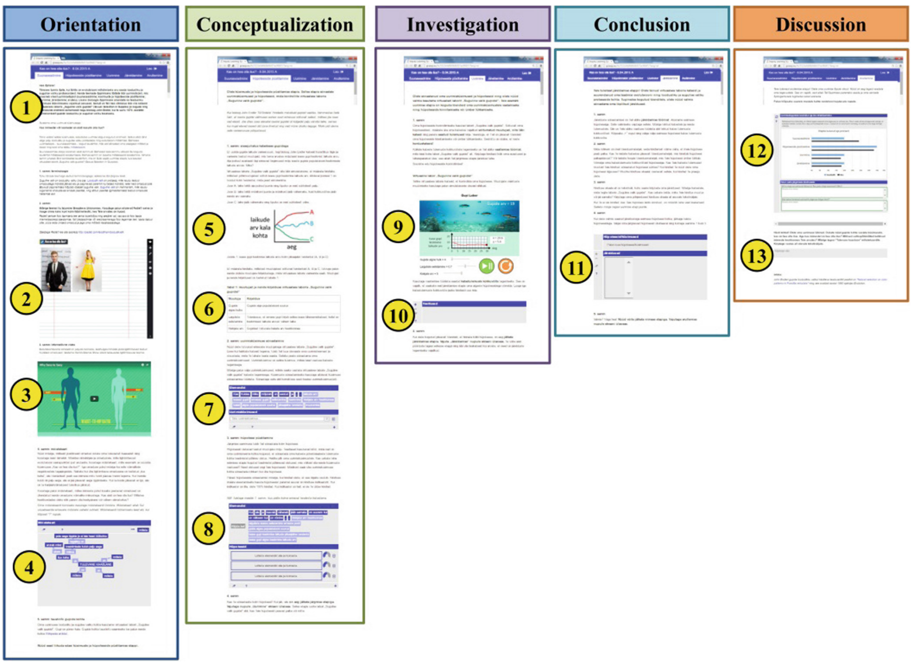

Fig. 2. Zoomed out screenshots of the five inquiry phases for the Go-Lab ILS *Is it good to be beautiful?* A detailed descriptions of the content in each of these phases is given in Table 1. Notable design elements that form the structure of the ILS include: (1) text, (2) Padlet wall, (3) YouTube video, (4) Concept Mapper app, (5) image, (6) table, (7) Question Scratchpad app, (8) Hypothesis Scratchpad app, (9) virtual laboratory, (10) Observation Tool app, (11) Conclusion Tool app, (12) Reflection Tool app, and (13) Input Box app.

Table 1. Sequence of tasks and their descriptions in the Go-Lab ILS *Is it good to be beautiful?* (http://www.golabz.eu/spaces/it-good-be-beautiful).

Inquiry phase	Task sequence	Task description
Orientation	Read about the objectives of the lesson	Students are introduced to the inquiry lesson. They are informed that in this phase they will gather background material to create a concept map. A puzzling question is asked to spark the curiosity of students: "Is it always good for a person or an animal to look beautiful?"
	Get familiar with key terminology	Relevant terminology (*natural* and *sexual selection*) is briefly defined and links to more exact definitions on the internet is provided
	Use the Padlet app to share digital information	Students are instructed to contribute to a classroom discussion by adding a picture of a person they think is beautiful to a virtual "wall" (on Padlet.com)
	Watch a short video	Students watch a 3 ½ min long YouTube video about 'Why Sexy is Sexy'
	Create a concept map	Students are instructed to think about the characteristics of their ideal spouse and complete a partially filled-in concept map using the Concept Mapper app. For each characteristic they need to identify both positive and negative concepts (e.g., a sexy body arouses me; a sexy body suggests my potential spouse spends too much time exercising and not enough time studying)
	Read additional material	Students are instructed to read about guppy fish and then move on to the conceptualization inquiry phase
Conceptualization	Read about the aims of the conceptualization phase	It is explained to students that in this phase they will formulate research questions and hypotheses that will be tested using a virtual laboratory. They are introduced to a study made by biologist John Endler when he investigated the balance of natural and sexual selection in guppy fish in the 1970s
	Visualize the dependent variable from a figure	A figure is used to illustrate how the dependent variable (i.e. average number of spots per male guppy) can vary with time in different ways depending on the influence of independent variables in the environment
	Visualize independent variables from a table	A table is used to list the independent variables that can be changed in the virtual laboratory (i.e. initial number of guppies, female preference for spotted guppies, number of predators in the environment)

(*continued*)

Table 1. (*continued*)

Inquiry phase	Task sequence	Task description
	Formulate research question(s)	Students are instructed to formulate research question(s) using the Question Scratchpad app
	Formulate hypotheses	Students are instructed to generate hypotheses using the Hypothesis Scratchpad app and then move on to the investigation inquiry phase
Investigation	Read about the aims of the investigation phase	It is explained to students that the main goal of the investigation phase is to collect evidence that can be used to confirm or reject their hypotheses
	Interact with the virtual lab to perform experiments	Students are instructed to perform experiments with the virtual laboratory. The lab allows students to vary three independent variables and observe the effects visually on a graph showing how the dependent variable changes with time
	Record observations	Students are instructed to record their observations using the Observation Tool app. Students are reminded to make as many experiments as needed to address their hypotheses, and once finished proceed to the Conclusion inquiry phase
Conclusion	Read about the aims of the conclusion phase	Students are instructed to draw conclusions in this phase based on the evidence they previously collected
	Draw conclusion(s)	Students are instructed to use the Conclusion Tool app to make conclusions(s). The app allows them to see their research questions and hypotheses made in the conceptualization inquiry phase and their observations made in the investigation phase
Discussion	Read about the aims of the discussion phase	It is explained to students that reflection is an important learning strategy for improving their future performance in inquiry and that communicating knowledge is an important part of how scientists work
	Reflect on inquiry experience	Students are instructed to use the Reflection Tool app to look at their time spent in each inquiry phase and reflect on two questions: (1) Which inquiry phase was the most difficult for you and why?; and, (2) What would you do differently the next time you conduct an inquiry investigation?
	Answer the question ‘Is it good to be beautiful?’	The Input Box app is used to ask a final open response question: Is it good to be beautiful?
	Read optional reference material	An internet link to the original research article published by John Endler is provided

The virtual laboratory was integrated into the Go-Lab learning environment via creation of an ILS called *Is it good to be beautiful?* Our study used an Estonian language ILS but an equivalent English language version can be found at http://www.golabz.eu/spaces/it-good-be-beautiful. The ILS was designed following the inquiry-based learning framework of Pedaste et al. (2015) to include the five general inquiry phases [12]. The phases can be individually navigated using "tabbed" browsing on smart devices. Figure 2 shows zoomed out screenshots of the five inquiry phases and notable design elements. Table 1 provides a detailed description of the lesson plan used for this ILS.

The Go-Lab intervention included two conditions: one condition where inquiry apps (Question Scratchpad and Hypothesis Scratchpad) in the conceptualization phase of the ILS displayed predefined terms to help students formulate research questions and hypotheses, and the other condition where the inquiry apps did not display these terms. The predefined terms condition explicitly listed independent and dependent variables relevant to the virtual laboratory. Students were randomly assigned to one of the two conditions.

Assessment of inquiry skills was performed using paper-based tests administered a few days before and after the Go-Lab intervention. Items measuring *identifying variables* and *identifying and stating hypotheses* from the Test of the Integrated Science Process Skills (TIPS) and the TIPS II test were used [14, 15]. TIPS was used as the pretest and TIPS II as the posttest. Students were allotted about twenty minutes to complete the 21 multiple choice items in each test.

3 Results and Discussion

The results of the inquiry skills pre- and posttests are presented in Table 2. A Wilcoxon signed-rank test was conducted to check for differences in pre- to posttest scores. The test showed significant increases in scores for students in the *with* predefined terms condition ($Z = -3.516$, $p < 0.05$), as well as for students in the *without* condition ($Z = -3.059$, $p < 0.05$).

Table 2. Descriptive statistics of the inquiry skills pre- and posttest scores for students in the conditions with and without predefined terms in the Question and Hypothesis Scratchpad apps.

Inquiry skills test score	With ($N = 16$)		Without($N = 12$)	
	Mean	Std. Dev.	Mean	Std. Dev
Pretest score	12.38	2.53	12.00	2.73
Posttest score	13.75	2.21	13.08	1.08
Gain score	*1.37*	*2.73*	*1.08*	*3.23*

One explanation why students' inquiry skills improved in both conditions is that students aged 16 to 19 are already familiar with stating research questions and hypotheses, and including predefined terms as additional scaffolding support is unnecessary. Alternatively, it may be that the overall ILS design provided enough support for students to identify the key independent and dependent variables when formulating their research questions and hypotheses. Either way it is important to emphasize that the content of the digital lesson was not directly related to the content assessed by the inquiry skills tests. For example, a representative test item in TIPS II reads as follows:

Some students are considering variables that might affect the time it takes for sugar to dissolve in water. They identify the temperature of the water, the amount of sugar and the amount of water as variables to consider. What is a hypothesis the students could test about the time it takes for sugar to dissolve in water?

1. *If the amount of sugar is larger, then more water is required to dissolve it.*
2. *If the water is colder, then it has to be stirred faster to dissolve.*
3. *If the water is warmer, then more sugar will dissolve.*
4. *If the water is warmer, then it takes the sugar more time to dissolve.*

As the above example helps illustrate, the inquiry skills items are domain-general and do not evoke subject-specific knowledge. Instead they aim at assessing students' comprehension of a set of practices (i.e. identifying and stating hypotheses, identifying variables) needed to engage successfully in scientific inquiry.

From researcher observations made during the intervention, students appeared to be engaged with the inquiry tasks and progressed in a timely manner through each of the inquiry phases. These observations were made in part using the "teacher" view in the Go-Lab platform, which allows an ILS author to view the work done by individual users who have accessed that ILS. More advanced functionality, such as Go-Lab learning analytics apps, allow ILS authors to view exactly how much time users spent in an inquiry phase and the number of actions they made using Go-Lab inquiry apps.

On the whole, it appeared that the five general inquiry phases helped structure learning for students and kept them engaged with an assortment of tasks associated with scientific inquiry practices. This Go-Lab inquiry cycle framework is similar to how the WISE web-based inquiry science environment applies the knowledge integration framework [16] to structure its learning tasks, and which also has shown to be effective in inquiry-based science lessons [17]. However, the reliance of many WISE units on Flash (.swf) and Java (.jar) objects does not make it a suitable for use with smart devices. In contrast, the prominent use of HTML5 components in the Go-Lab environment makes it quite compatible with smart devices. Moreover, the modular design of inquiry tasks in five different inquiry phases and scaffolded with various inquiry apps can help facilitate navigation and learning for smart device users. Overall, the Go-Lab Platform provides a new and useful environment for educators to design smart device compatible learning experiences to improve students' inquiry skills.

4 Conclusion

In summary, this study demonstrated an example of smart device use in the science classroom by which students improved their inquiry skills. A digital lesson created in the Go-Lab environment consisting of five inquiry phases appeared to engage students in the scientific reasoning processes necessary for successful inquiry learning. Future research could benefit from also studying if, in addition to better academic outcomes, students exhibit more positive attitudes towards science after engaging in inquiry learning using smart devices.

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