Enhancing pre-service science teachers' inquiry skills in hands-on and virtual laboratory environments

Hasan Ozgur Kapici, Hakan Akcay
hokapici@yildiz.edu.tr, hakcay@yildiz.edu.tr

Department of Mathematics and Science Education, Faculty of Education, Yildiz Technical University

Abstract

Rapid developments in educational technology show its impacts on classes. One of the recent trends in science education is virtual laboratory environments. The goal of this study is to reveal the effects of inquiry-based hands-on and virtual laboratory environments on pre-service science teachers' inquiry skills. A quasi-experimental research design was used in the current study. There were a total of 42 pre-service science teachers as participants. Whereas 21 of them were taught in the hands-on laboratory environment, the other 21 pre-service science teachers were instructed in the virtual laboratory environment. The guided inquiry-based approach was used. The experiments were from physics and chemistry domains. Due to the limited number of participants in each condition, the nonparametric versions of the parametric tests were used in this study. The findings showed that the inquiry skills of pre-service science teachers in the two conditions enhanced significantly. There was no significant difference between the conditions. This result shows that hands-on laboratories can be replaced by virtual laboratories to enhance pre-service science teachers' inquiry skills.

Keywords: Hands-on laboratory, virtual laboratory, inquiry skills, pre-service science teachers

Introduction

Reaching high quality in science education is an important aim for nations because today's students will become scientists, engineers or technical workers to create innovations for enhancing a nation's economic growth and international competitiveness (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2007; National Research Council, 2011). One of the influential ways to achieve high-quality science education is by providing a student-centered learning approach such as inquiry-based learning. Students' inquiry through investigations initialized by students' owns questions not only enables them to have a deeper conceptual understanding (NGSS, 2013) but also enhances their higher-order skills such as metacognition and argumentation (Dori & Sasson, 2008; Kaberman & Dori, 2009).

In the current study, we investigated how different laboratory environments (hands-on and virtual laboratories) affect pre-service science teachers' inquiry skills. In particular, we focused on which type of laboratory environments has a more significant impact to enhance pre-service science teachers' inquiry skills. Two conditions involved in the study and quasi-experimental research design was used. An inquiry-based learning approach was used for the two conditions. Whereas the structured laboratory worksheet was acted as guidance in the hands-on laboratory environment, online scaffolding tools were used for the students in the virtual laboratory. The instructor was also guidance for both of the conditions.

Theoretical background

Knowledge is constructed actively by hands-on and minds-on activities in a constructivist approach (Cakir, 2008). Laboratories are environments where students can reach and shape their own knowledge and understanding by involving in inquiry activities (Gabler & Schroeder, 2003). In other words, school science laboratories are one of the key factors for application of constructivism successfully (Correiro, Griffin & Hart 2008).

Inquiry-based school science laboratories

School science laboratories are crucial learning environments not only for conceptual understanding but also for improving the inquiry skills of students. They are especially important for inquiry-based learning if used properly (Hofstein & Lunetta, 2004). Minner, Levy and Century (2010) state that inquiry refers to three different categories of activities, which are what scientists do, how students learn and a pedagogical approach followed by teachers (p. 476). Minner et al. (2010) explain the category of what scientists do as conducting investigations done by using scientific method, the category of how students learn as actively participating hands-on and minds-on activities, and lastly defining the category of a pedagogical approach as using curriculum which enables teachers to encourage their students in order to conduct extended investigations. Science-A-Process Approach (SAPA), which is a curriculum project, categorized the inquiry skills into two classes which are basic skills and integrated skills (Padilla, 1990). Basic skills were defined as making an observation, inferring, measuring, communicating, classifying, and predicting. These are the basis for integrated skills, which are more complex such as *forming a hypothesis, identifying and changing variables, analyzing data, designing and implementing experiments* (Padilla, 1990, p. 1-2).

National Research Council (NRC, 2000, p. 25) also proposes five criteria as essential features of classroom activity. These are as follows:

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their explanations in the light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations.

The criteria listed above affect students in two ways: (i) enhancing their content knowledge and (ii) developing their skills and abilities (Bybee, 2000). Because students are able to be involved in the processes such as identifying problems, designing experiments, and defending arguments based on the data gathered from the investigations, inquiry-based school science laboratories are central to learning science (Hofstein & Walberg, 1995). However, students usually have trouble in inquiry-based school science laboratories since these kinds of environments necessitate the effective use of cognitive and metacognitive skills. For this reason, students may need guidance in such a learning environment. A recent meta-analysis was done by Lazonder and Harmsen (2016) also revealed that the efficiency of inquiry-based learning depends mostly on the availability of proper guidance. De Jong and Lazonder (2014) presented a typology of guidance concerning students' need to achieve in inquiry-based learning environments. These are *process constraints, performance dashboards, prompts, heuristics, scaffolds* and *direct presentation of information* (p. 375-379). The types of guidance provided for students might change based on students' age. For example, more open types of guidance (i.e., prompts, scaffolds) are more suitable for older students (de Jong & Lazonder, 2014). Furthermore, the way providing scaffolding differ concerning the laboratory environment. Whereas online scaffolding tools are mostly used in virtual laboratories, their equivalents in written form are used in hands-on laboratories.

Hands-on and virtual laboratory environments

Although hands-on laboratories have been using in schools commonly, virtual laboratories have also started to be used in school science laboratories due to dramatic developments in educational technology. Both types of laboratory environments mainly have the same goals for students. Yet, the ways they presented are different from each other. For example, in the hands-on laboratory environment, physicality is required to gather data by observing, measuring, and so on. In other words, students are able to touch the materials and apparatus which help them to develop their practical skills (de Jong, Linn & Zacharia, 2013). This is also important to improve students' psychomotor skills (Kontra, Lyons, Fischer & Beilock, 2015). On the other hand, virtual laboratories have their own affordances. For instance, it is possible to take out the detailed information and students can focus on the main parts of the topic (Trundle & Bell, 2010), invisible concepts can be transformed into concrete forms such as electricity (Kollöfel & de Jong, 2013), it provides time and cost efficiency and safe environment (Hsu & Thomas, 2002), and it is also proper to integrate online scaffolding tools (de Jong, Sotiriou & Gillet, 2014). However, although virtual laboratory environment has much potential to enhance students' inquiry skills, it also has some disadvantages such as *dictating the direction of inquiry by predefining variables* (Mustafa & Trudel, 2013, p. 124), and it is not possible to test alternative models or novel variables (Dalgarno & Lee, 2010; Machet, Lowe & Gütl, 2012).

Comparison of hands-on and virtual laboratory environments on students' inquiry skills

There are several studies in which the effects of laboratory environments on students' inquiry skills. For example, Kapici, Akcay and de Jong (2019) found that whereas middle school students who were taught in the virtual laboratory environment improved their inquiry skills significantly, their counterparts in the hands-on laboratory environment did not. Similarly, Yang and Heh (2007) concluded that virtual laboratories have significant impacts on tenth-grade students' inquiry skills. Clarke (2010) also stated that 55% of the participants in her study from middle and high schools increased their inquiry skills. On the other side, Ratamun and Osman (2018) found that fourth grade students in the hands-on laboratory improved their inquiry skills better than the ones in the virtual laboratory. Another study, by Mustafa and Trudel (2013), reported that high school students significantly developed their inquiry skills independently of laboratory environments. All these studies show contradictive results about the effects of laboratory environments on students' inquiry skills.

The other important conclusion based on these studies is none of them involved pre-service science teachers as participants. Indeed, promoting pre-service science teachers' inquiry skills is an important issue because they are going to be professional science teachers in their future careers. They can encourage their students to develop inquiry skills efficiently if they have advanced inquiry skills. The teaching of science that pre-service science teachers have exposed as students in middle or high school or undergraduate levels are some major learning environments to experience inquiry learning (Bencze, Bowen & Alsop, 2006; Friedrichsen, Munford & Orgill, 2006). These experiences may have a positive or negative impact on pre-service teachers' confidence in using inquiry in his/her class (Flores & Day, 2006).

There are several ways to develop pre-service science teachers' positive disposition inquiry. For instance, a context can be provided for pre-service science teachers in which they can enhance their own conceptual understanding and an understanding of the difficulties they will face in using inquiry (Melville, Fazio, Bartley & Jones, 2008). Handelsman et al. (2004) advocate that if science teachers are expected to use an inquiry-based approach successfully, then they must be allowed to experience the approach.

These two ideas (transmitting the inquiry skills to students, if the teacher has, and limited number of studies done with pre-service science teachers) make the current study valuable. The goal of the current study is comparing pre-service science teachers' inquiry skills acquisition regarding the laboratory environments. Based on this, the following research question was determined:

- Do pre-service science teachers who learned in a hands-on laboratory or a virtual laboratory differ in their acquisition of inquiry skills?

Method

Participants

The study was done with pre-service science teachers from a public university. The same instructor taught for both of the conditions. There were a total of 42 pre-service science teachers, whose ages were between 21 and 23. The study was based on a quasi-experimental research design. The groups were coded as H, in which pre-service science teachers were taught in a hands-on laboratory environment, and coded as V, where pre-service science teachers were instructed in a virtual laboratory environment. There was the same number of pre-service science teachers in each group (21 pre-service science teachers per condition). All of the pre-service science teachers had prior experience with computers.

Hands-on and Virtual Laboratory Environments

The virtual environments used in the current study were from the Go-Lab platform (Go-Lab Sharing and Authoring Platform, 2015). The purpose of the Go-Lab platform is to facilitate the use of innovative educational technologies in STEM education by focusing on inquiry learning tools and virtual laboratories. The platform has three main components: Labs, apps, and spaces. In the labs component, there are more than 750 virtual or remote laboratories related to physics, chemistry, biology, astronomy, environmental education, engineering, and technology. Whereas remote laboratories enable students to experiment with real equipment from remote locations, virtual laboratories offer an opportunity to simulate scientific investigations. The Appendices A and B present some views from the virtual laboratories used in the current study.

In the apps component, many scaffolding tools aim to help students in their inquiry learning path such as developing a hypothesis, designing an experiment or interpreting data. For example, in Figure 1, the hypothesis scratchpad used for the pre-service science teachers in the V condition is shown.

The last component of the platform is the spaces. It is called Inquiry Learning Space (ILS) on the platform. It is a personalized learning environment for students, in which virtual laboratories and scaffolding tools are combined. The main goal of an ILS is to encourage students to design and implement scientific investigations, being guided through the inquiry process. The basic form of an ILS consists of the phases of orientation, conceptualization, investigation, conclusion, and discussion. Figure 2 presents a screenshot of the Inquiry Learning Space (teacher view). Figure 3 presents a screenshot of the orientation phase (student view).

For the pre-service science teachers in the H condition, a hands-on laboratory environment was used. The physical forms of the equipment and laboratory worksheets were provided for them. In Figure 3, for instance, the equivalent form of the online hypothesis scratchpad in the laboratory worksheet is shown.

Data gathering tool

The multiple-choice inquiry skills test developed by Çelik (2013) was used in this study. The test includes 35 questions and is intended to measure pre-service science teachers' inquiry skills related to forming a hypothesis, inferring, identifying and controlling the variables, designing and implementing investigations. The numbers of questions related to corresponding inquiry skills are as follows: 12 questions are about identifying and controlling the variables, seven questions are about forming a hypothesis, five questions are about inferring, four questions are related to operational definitions, four questions are about designing and implementing experimentations and three questions are about data analysis. Cronbach's alpha coefficient was 0.98 for the inquiry skills post-test. Each correct answer was given one point.

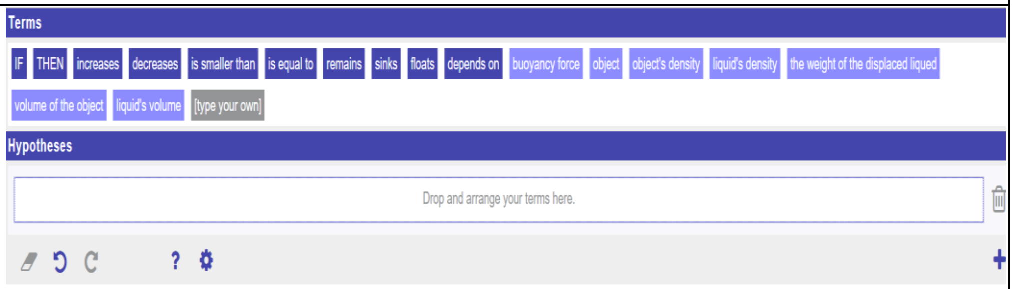
Laboratory Environment	Scaffolding Tool
Hypothesis Scratchpad provided for the PSTs in the virtual laboratory	
Hypothesis Tool provided in the laboratory worksheet for the PSTs in the hands-on laboratory	**Terms** - sinks - floats - buoyancy force - equal to - liquid's density - decreases - remains - increases - the weight of the displaced liquid - object's density - if - then - object - the volume of the object - liquid's volume Write your hypothesis into the given box.

Figure 1. Hypothesis scratchpad used in the virtual laboratory and its equivalent in the laboratory worksheet (The concepts in the figure translated from Turkish)

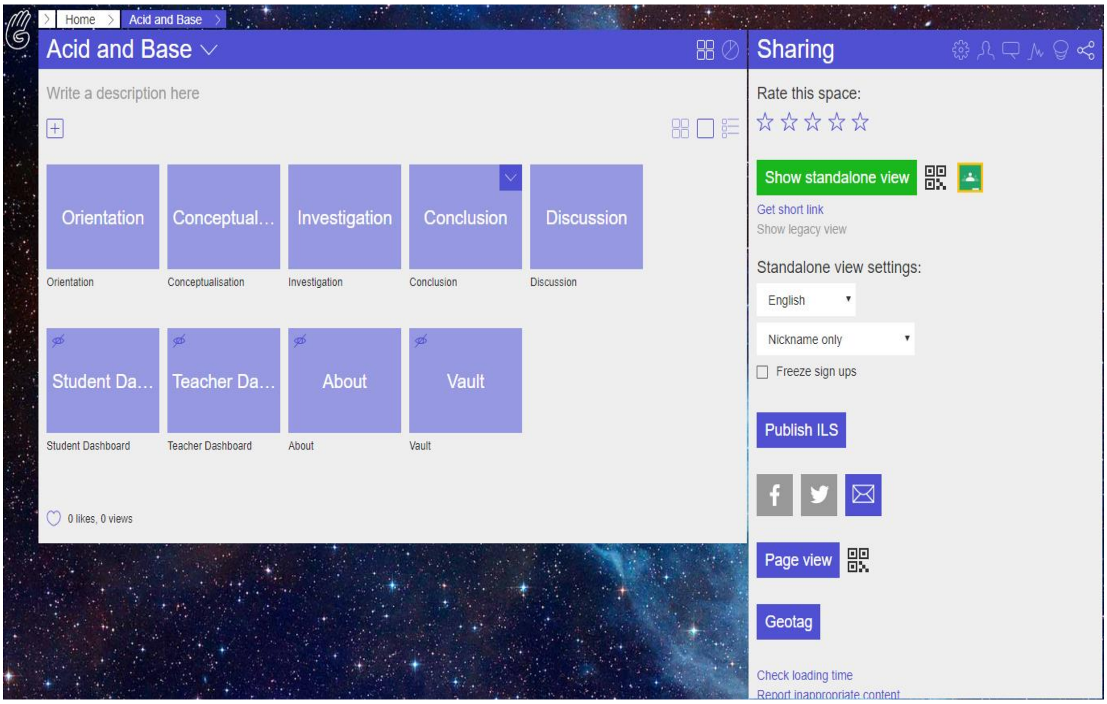


Figure 2. Inquiry Learning Space (teacher view)

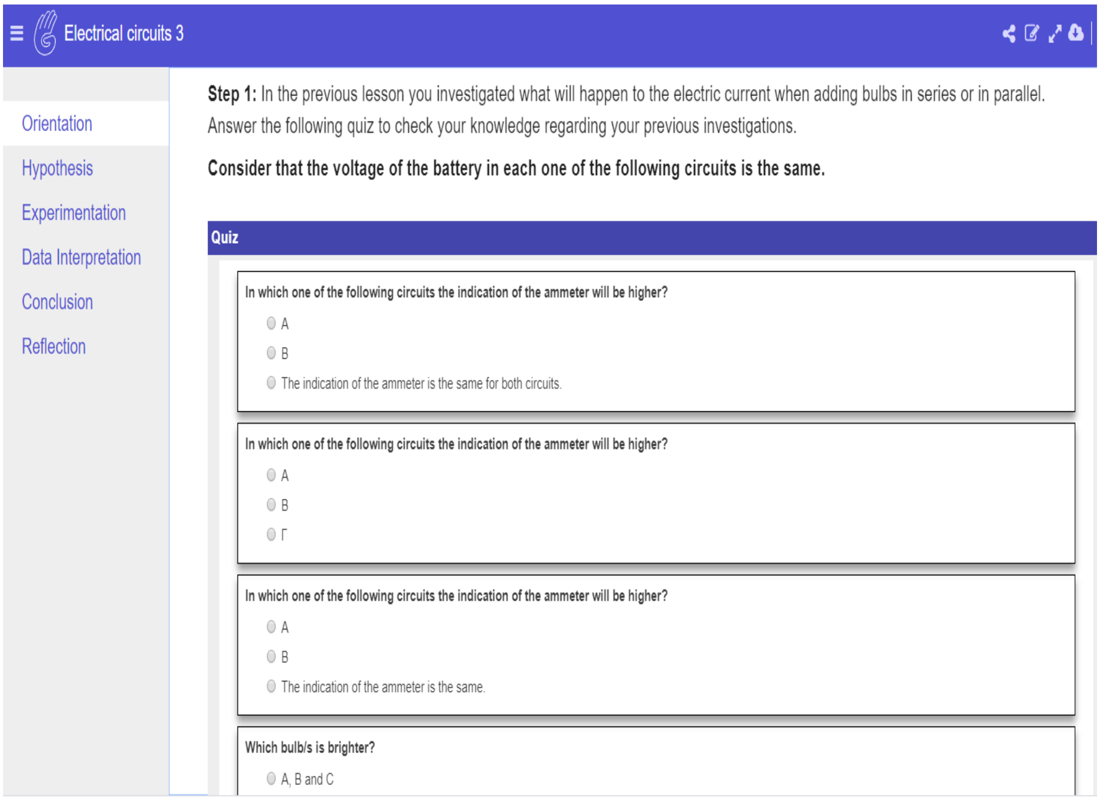


Figure 3. Orientation phase (student view)

Research design and implementation

The two classes were assigned randomly to one of the conditions in the study. The class coded as H was taught in the physical laboratory and designed and implemented investigations through hands-on activities. On the other side, the other class coded as V was taught in the computer laboratory and performed their experiments in the virtual laboratory. After assigning the classes into one of the conditions, the multiple-choice inquiry skills test was taken as a pre-test. Some exercises about the virtual laboratory platform were done with the pre-service science teachers from the class coded as V. The aim of such exercises was to introduce the virtual laboratory environment for the pre-service science teachers. Some basic technical properties of the virtual environment were provided and pre-service science teachers' questions about the virtual laboratory environments were replied. The virtual platform was not introduced to the pre-service science teachers in the class coded as H.

The study lasted for eight weeks. In the first three weeks, inquiry skills and 21st century skills were defined and discussed based on the articles. After this, pre-service science teachers were taught and did their investigations concerning the laboratory environment designated for their class' assigned condition for the next five weeks. The topics were from chemistry (chemical solutions and acid and base) and physics (electricity, buoyancy force, and fluid pressure). The pre-service science teachers in the two classes did all the experiments and took the pre-test and post-test individually.

An inquiry-based learning approach was used in the classes. The inquiry cycle defined by de Jong (2006) as orientation, hypothesis generation, experimentation, conclusion, and evaluation was followed. Paper-based laboratory worksheet was used for the class coded as H and online scaffolding tools were used for the class coded as V. The instructor was same for both of the classes and also acted as guides for the pre-service science teachers. Pre-service science teachers received scaffolding in three stages of the inquiry cycle, which are forming a hypothesis, experimentation, and conclusion. The online scaffolding tools and their paper-based forms were equivalent to each other (for example, see Figure 1).

Table 1. Descriptive results for the inquiry skills test with respect to the classes (max: 35)

Classes	Pre-test Mean (SD)	Post-test Mean (SD)
H	18.05 (5.53)	23.48 (3.41)
V	16.10 (3.82)	23.62 (3.25)

Data analysis

Due to the limited number of participants in each condition, the Wilcoxon-signed-rank test and Mann-Whitney U test were used to analyze the data. Wilcoxon-signed-rank test was used to compare each group's pre-test and post-test scores. Furthermore, the Mann-Whitney U-test was used to reveal whether there is a significant difference between the classes.

Results

The results of descriptive statistical analysis are presented in Table 1. The values of Mann-Whitney U-test and Wilcoxon-signed-rank are also given.

Firstly, the pre-service science teachers' in the class coded as H pre-test and post-test scores were compared by using the Wilcoxon-signed-rank test to understand whether there is a significant difference in the participants' inquiry skills from the beginning of the study to the end. A Wilcoxon-signed-rank test indicated that post-test ranks were statistically significantly higher than pre-test ranks Z=3.27, p=.001. A similar path was followed for the pre-service teachers' in the class coded as V pre-test and post-test results. A Wilcoxon-signed-rank test indicated that post-test ranks were statistically significantly higher than pre-test ranks Z=3.85, p=.000. The findings revealed that pre-service science teachers' inquiry skills developed significantly independently of the laboratory environments.

After this, the classes' pre-test scores were compared by using the Mann-Whitney U-test to understand whether there is any significant difference between pre-service science teachers' inquiry skills from the two classes at the beginning of the study. The pre-tests result showed that there was no significant difference between the pre-service science teachers' inquiry skills in the class coded as V (*Mdn*=18.79) and their counterpart in the class coded as H (*Mdn*=24.21), U=163.5, p=.150.

Table 2. Descriptive results for the inquiry skills test tested in the test concerning the classes

Class		Forming hypothesis (7 items)	Inferring (6 items)	Analyzing data (3 items)	Experimentation (4 items)	Operational definition (4 items)	Identifying and controlling the variables (12 items)
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
H	***Pre-test***	*3.48 (1.26)*	*2.33 (1.17)*	*0.67 (0.47)*	*2.71 (0.96)*	*2.62 (1.02)*	*6.24 (3.45)*
	Post-test	*3.90 (1.51)*	*2.95 (0.95)*	*0.71 (0.55)*	*3.43 (0.68)*	*2.76 (0.99)*	*9.71 (1.95)*
V	**Pre-test**	3.48 (1.50)	2.52 (1.10)	0.57 (0.47)	3.00 (0.89)	2.24 (1.04)	4.29 (2.24)
	Post-test	4.66 (0.94)	2.76 (0.87)	0.67 (0.66)	3.86 (0.36)	2.67 (0.97)	8.95 (2.11)

The same test was implemented for the post-test scores of each group. Similarly, the results of the post-test indicated that there was no significant difference between the pre-service science teachers' inquiry skills in the class coded as V (*Mdn*=21.36) and the pre-service science teachers in the class coded as H (*Mdn*=21.64), *U*=217.5, *p*=.940. The findings revealed that hands-on and virtual laboratories are equally effective to enhance the inquiry skills of pre-service science teachers.

The analysis was also done concerning the inquiry skills involved in the inquiry skills test. Table 2 shows descriptive data based on inquiry skills. For the forming hypothesis, although the pre-service science teachers in the V class improved their score better than their counterparts in the H class, this was non-significant (*U*=160.5, *p*=.116).

For the inferring, Mann Whitney U tests revealed that there were no significant differences between pre-service science teachers' scores for both at the beginning and end of the study, respectively (*U*=190.5, *p*=.427; *U*=190.5, *p*=.424). For the analyzing data, we did not reach any significant difference between the classes at the end of the study (*U*=220.5, *p*=.999). ın terms of experimentation skill, although there was no significant difference between the classes at the beginning of the study (*U*=175.0, *p*=.220), pre-service science teachers in the V class improved their skill significantly better than the ones in the H class at the end of the study (*U*=144.0, *p*=.017). For the operational skills, a non-significant difference revealed at the end of the study (*U*=207.0, *p*=.720). The last skill tested in the study was identifying and controlling the variables. It was found that there were no significant differences between pre-service science teachers' scores for both at the beginning and end of the study, respectively (*U*=148.0, *p*=.066; *U*=173.5, *p*=.231).

Discussion

In this study, we compared the effects of hands-on and virtual laboratory environments on pre-service science teachers' inquiry skills. The findings revealed that laboratories have a significant role in enhancing pre-service science teachers' inquiry skills because the participants from both conditions improved their skills significantly when they were taught in hands-on or virtual laboratory environments. School science laboratories provide opportunities to students such as observation, designing and implementing experiments, gathering and analyzing data, and reaching a conclusion which is some of the main phases of inquiry-based learning approach (Hofstein & Lunetta, 2004; Hofstein & Walberg, 1995).

On the other side, it cannot be said that inquiry-based learning in school science laboratories always give favorable outcomes on students' inquiry skills and/or domain knowledge (see, e.g., Klahr & Nigam, 2004). In the study done by Kirschner, Sweller and Clark (2006), they claimed that the ineffectiveness of an inquiry-based approach can be due to ignoring the capacity of working memory, which is an important cognitive structure for learning. In order to deal with such problems, one of the crucial requirements is providing scaffoldings (Hmelo-Silver, Duncan & Chinn, 2007). For this study, one of the main reasons to enhance pre-service science teachers' inquiry skills in different inquiry-based laboratory environments can be encouraging them through the learning process with proper scaffolding tools depends on their laboratory environments. De Jong and van Joolingen (1998) found the most effective three guidance tools through an inquiry-based learning process in their study. These are enabling learners to reach information directly, providing assignments to construct their inquiry process, and using the model progression to simplify the complex process of inquiry learning. In the current study, we tried to provide some of these powerful tools for pre-service science teachers. For example, the instructor demonstrated the main steps of designing an electrical circuit for the pre-service science teachers in the hands-on laboratory environment. For the ones in the virtual laboratory environment, a short demonstration video about designing an electrical circuit was provided. This might be another reason for the results of this study.

It was also reached that there was no significant difference between hands-on and virtual laboratory environments on pre-service science teachers' inquiry skills. This result shows that hands-on laboratories can be replaced by virtual laboratories to enhance the inquiry skills of pre-service science teachers. Science teachers usually face difficulties when designing and implementing investigations in a hands-on laboratory environment due to restrictions related to the laboratory environment (Nivalainen, Asikainen, Sormunen & Hirvonen, 2010). For example, the high cost of lab equipment and materials, single-use school space for hands-on labs, the potential dangers and liabilities of using chemicals, tools, and other lab materials, and the use of precious classroom hours to set up traditional experiments are some possible restrictions of hands-on laboratory environments (Scalise et al., 2011). To deal with such limitations, virtual laboratory environments can offer time- and cost-efficient, and safe solutions (Hsu & Thomas, 2002). That's why, it is possible to use virtual laboratory environments as much as hands-on laboratory environments to enhance learners' inquiry skills.

The unique significant difference was found for experimentation skills for pre-service science teachers in the V class. This can be due to the advantages of a virtual laboratory environment because pre-service teachers in this condition were able to design and implement more experiments in a limited time.

Conclusions

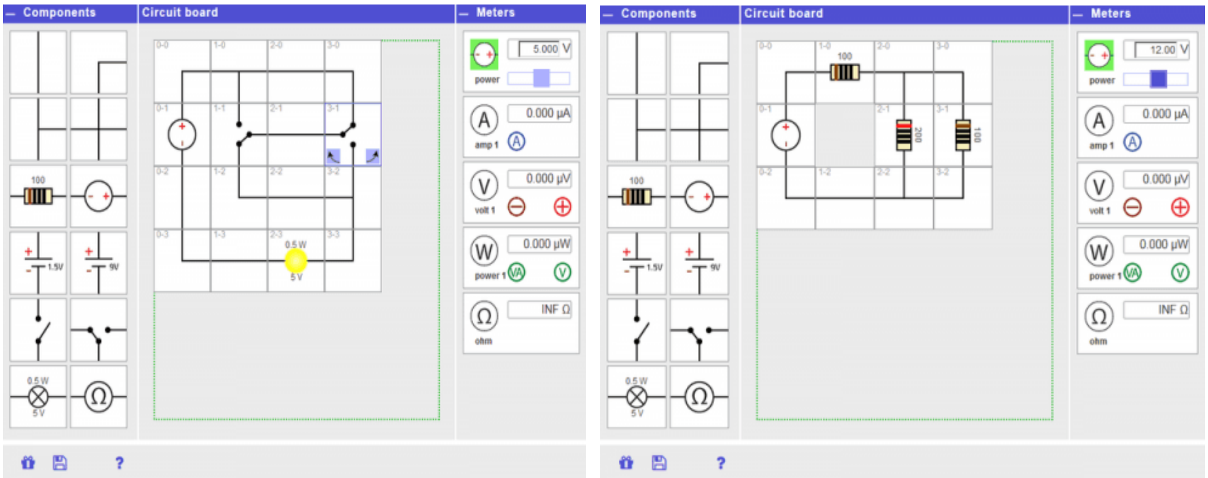
The overall results of the current study revealed that if learners are provided with proper guidance in the inquiry-based learning process, their inquiry skills develop significantly in both hands-on and virtual laboratory environments. It is an obvious fact that each (hands-on and virtual) laboratory environment has its own advantages. It is difficult to make a certain conclusion about which one of the laboratory environments is better than the other one. A science teacher/instructor should decide which type of laboratory environment fits better with the topic(s). Furthermore, in order to have science teachers who have qualified inquiry skills, technology can be used as a useful tool. That's why the courses related to technology integration into the learning environment can be developed in a teacher education program. Learning by design approach (Koehler & Mishra, 2005) can be an efficient solution to encourage pre-service teachers to use technology effectively for their future careers.

For further studies, the effects of combined versions of laboratory environments on learners' inquiry skills can be investigated. Similar studies can be done with a different topic and different level(s) of students. Moreover, different scaffolding tools can be added to inquiry learning to investigate how scaffolding affects students' inquiry skills improvement. After that, it can be clearer that which type of laboratory environment is more beneficial to enhance students' inquiry skills. Furthermore, this study had some limitations. For example, the pre-service science teachers in the virtual laboratory environment were naïve about the technology-enhanced learning environments since this was their first experience with such simulations. Besides, there were a limited number of pre-service science teachers in the study.

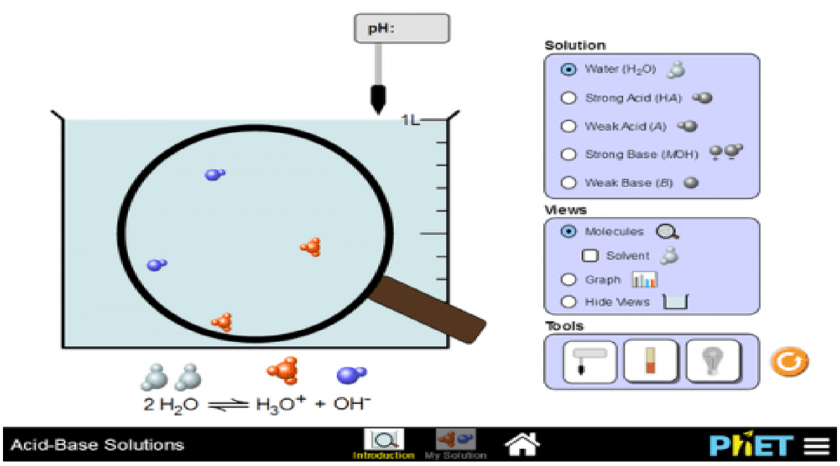
Note

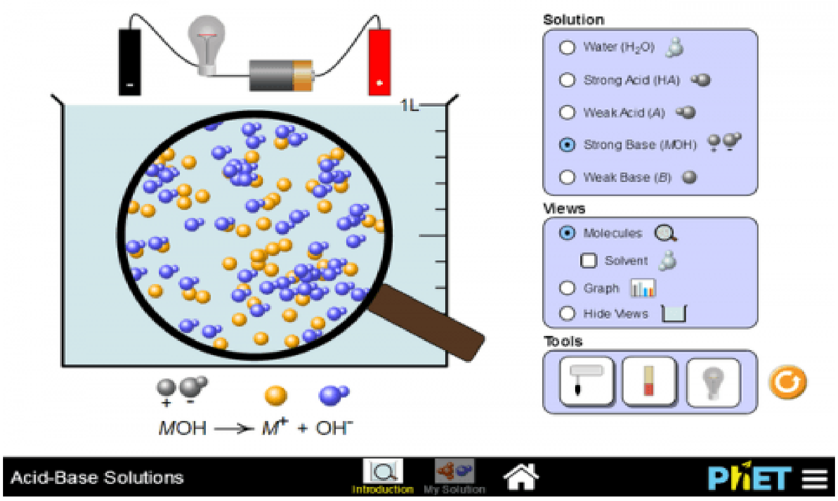
Part of this paper was presented at the International Conference on Education in Mathematics, Science and Technology (ICEMST), April 28 - May 1, 2019, Izmir, Turkey.

Appendix A. Go-Lab platform: Electrical Circuit Lab



Appendix B. Go-Lab platform: Acid-Base Solutions





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